

PHYSIOLOGICAL ATTRIBUTES AND YIELD OF WHEAT AS INFLUENCED BY IRRIGATION AND NITROGEN FERTILIZER APPLICATION



A Dissertation

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**DOCTOR OF PHILOSOPHY
IN
CROP PHYSIOLOGY AND ECOLOGY**

**DEPARTMENT OF CROP PHYSIOLOGY AND ECOLOGY
HAJEE MOHAMMAD DANESH SCIENCE AND TECHNOLOGY UNIVERSITY
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Submitted to

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MAY 2019



DEDICATED
TO
BELOVED
PARENTS

DECLARATON

I, **Md. Ziaul Haque**, hereby declared that the Dissertation entitled “**PHYSIOLOGICAL ATTRIBUTES AND YIELD OF WHEAT AS INFLUENCED BY IRRIGATION AND NITROGEN FERTILIZER APPLICATION**” submitted to the department of crop Physiology and Ecology, Hajee Mohammad Danesh Science and Technology University, Dinajpur in the fulfillment of the requirements for the degree of **DOCTOR OF PHILOSOPHY** in Crop Physiology and Ecology is a record of bonafide research designed and carried out by me. No part of this dissertation was produced elsewhere for any degree. It does not contain results of any collaborative study.

(Md. Ziaul Haque)



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CERTIFICATE

This is to certify that the work embodied in this thesis is an original research work done by **Md. Ziaul Haque** under my supervision for the degree of Doctor of Philosophy. The references cited in it have duly been acknowledged. The style and contents of the thesis have been approved and recommended for submission.

(Professor Dr. Md. Maniruzzaman Bahadur)
Supervisor

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The author

ABSTRACT

The experiment was conducted at the research farm and laboratory of Crop Physiology and Ecology Department, Hajee Mohammad Danesh Science and Technology University, Dinajpur, Bangladesh in 2014 - 2015 and 2015 - 2016 to study the morpho-physiological parameters, phenological stages, water relations, chlorophyll content, proline accumulation, nitrogen uptake, protein content, N use efficiency, yield and yield contributing characters of wheat. Benefit-cost ratio was calculated for cultivation of two varieties. Four levels of irrigations (i) I₀- Rain-fed condition (control) (ii) I₁- One irrigation (30 mm) (iii) I₂- Two irrigations (30+30 =60 mm) and (iv) I₃- Three irrigations (30+30+30 =90 mm) and four split application of nitrogen were (i) N₀- control (no nitrogen) (ii) N₁- total nitrogen at basal dose (iii) N₂- one third of the N fertilizer was applied at basal dose, one third of the N fertilizer was applied at crown root initiation stage and the rest was applied at maximum tillering stage and (iv) N₃- one fourth of the N fertilizer was applied at basal dose, one fourth of the N fertilizer was applied at crown root initiation stage, one forth was applied at maximum tillering stage and the rest was applied at heading stage. Two wheat varieties, namely, BARI Gom 24 and BARI Gom 26 were tested for the above mentioned parameters. The experiment was laid out in a split-split plot design with 3 replications. Irrigation and nitrogen treatments had significant effects on all above mentioned parameters in both the years. The plants grown in three irrigations (I₃) condition needed the highest days for attaining their different phenological stages. Three irrigations exhibited the highest crop growth, morpho-physiological traits, water consumption, chlorophyll content, yield contributing characters, nitrogen uptake, grain and straw yield of wheat. With some exceptions, varieties had no significant effects on all the above mentioned parameters in this study. Among the nitrogen treatments, the highest crop growth, morpho-physiological traits, yield contributing characters, nitrogen uptake, protein content, N use efficiency, grain and straw yield were recorded in three split (N₂) applications of nitrogen in both the years. Simple correlation coefficients between the yield contributing characters and grain yield for different irrigation and nitrogen treatments indicated that grain yield was positively correlated with yield components. In case of benefit-cost ratio, the highest benefit-cost ratio was found from BARI Gom 24 with three irrigations and three split applications of nitrogen. Wheat production with three irrigations gave the highest crop growth, morpho-physiological traits, water consumption, yield contributing characters, nitrogen uptake, grain and straw yield which were statistically similar with two irrigations. For the efficient use of nitrogen for wheat cultivation N fertilizer should be applied as three splits such as at basal, at CRI and during maximum tillering stages.

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ABBREVIATIONS AND ACRONYMS

AEZ	:	Agro Ecological Zone
@	:	At the rate of
Agric.	:	Agriculture
Agril.	:	Agriculture
BARI	:	Bangladesh Agricultural Research Institute
BBS	:	Bangladesh Bureau of Statistics
CIMMYT	:	Centro Internacional de Mejoramiento de Maíz y Trigo (International Wheat and Maize Improvement Centre)
cm	:	Centimeter
CRI	:	Crown Root Initiation
CV	:	Co-efficient of Variation
DAA	:	Days After Anthesis
DAS	:	Days After Sowing
Dept.	:	Department
DMRT	:	Duncan's Multiple Range Test
e.g.	:	For example
et al.,	:	And other
FAO	:	Food and Agriculture Organization
FW	:	Fresh Weight
g	:	Gram
ha	:	Hectare
HSTU	:	Hajee Mohammad Danesh Science & Technology University
LAI	:	Leaf Area Index
LAR	:	Leaf Area Ratio
LWR	:	Leaf Weight Ratio
RLGR	:	Relative leaf growth rate
SLA	:	Specific leaf area
RGR	:	Relative Growth Rate
m	:	Meter
MP	:	Muriate of Potash
NAR	:	Net Assimilation Rate
NARS	:	National Agricultural Research System

No	:	Number
RGR	:	Relative Growth Rate
Sci.	:	Science
SL.	:	Serial
TDM	:	Total Dry Matter
TSP	:	Triple super Phosphate
UNDP	:	United Nations Development Programme
viz.	:	Namely

CHAPTER 1

INTRODUCTION

Wheat (*Triticum aestivum* L.) is the world's most widely cultivated food crop. It is the most important food grain and ranks first in terms of global consumption and production of food crop known as king of cereals (Costa, *et al.*, 2013). Wheat is grown across a wide range of environments around the world. More lands are devoted world-wide to the production of wheat than to any other commercial crop. Wheat is cool-loving crop and adopted for cultivation in regions with cooler climatic conditions. FAO (2013) indentified wheat as the key to the emergence of urban societies for millennia. About two thirds of the world population lives on wheat grains. It is eaten in various forms by more than one thousand million human beings in the world. Wheat is considered as the king of cereal crop because its cultivation is easier, nutrient content is higher and ecologically suitable. Wheat makes as larger contribution of proteins and calories to man than all other foods or cereal crops. It is the most important source of concentrated carbohydrate for human being and it contains considerable amount of protein, minerals and vitamins. It is not only used as human food but also as feed for livestock and raw materials for industrial products. Currently about 65% of wheat crop is used for food, 17% for animal feed and 12% in industrial products (FAO, 2013). Wheat starch is used for laundering, paper laminating and corrugating, adhesives, textiles, wallpaper, billboard paste and paper additives. CIMMYT predicted that demand for wheat in the developing world is projected to increase 60% by 2050 from now (CIMMYT, 2013). It contains carbohydrate (69.4%), protein (12.1%), minerals (2.7%), fat (1.7%) and considerable proportion of vitamins (Bakhru 1996).

Bangladesh has been running short of food and the gap between production and requirements is getting wider with the increase in population. Wheat area and production has decreased by 0.34 million hectares and 0.47 million tons, respectively, while unit yield has increased by 0.7 ton per hectare from 2000 to 2014 (Mundi Index, 2014). So, the possibility of increasing production by extensification of land is practically very little in Bangladesh, the means for increasing crop yields should be explored. Increasing agricultural production per unit area of land is becoming most important step to cope with the present population growth in Bangladesh. Wheat can be a good supplement of rice and it can play a vital role to feed this vast population. From nutritional point of view, wheat is superior to rice for its higher protein content. In Bangladesh, wheat is the second important cereal crop next to rice (Al-Musa *et*

al., 2012) and the area under wheat cultivation during 2012 was about 0.47 million ha and producing 1.38 million ton of wheat with an average yields of 3.32 ton ha⁻¹ (BBS, 2013). But the average yield of wheat is very low compared to the average yield of New Zealand, Netherlands, Ecuador, and France (8.9, 8.6, 8.0, and 7.6 t ha⁻¹ respectively) (FAO, 2013). The average yield of wheat in Bangladesh can be raised up to 6.8 t ha⁻¹ (BARI, 2010). Consumption rate of wheat is increasing day by day due to its low production cost, good market price and nutrition value. However, horizontal expansion of wheat area is not possible in Bangladesh due to limited land resources and high population density. So, there is an ample opportunity to increase production of wheat per unit area through adoption of modern and improved agronomic practices such as optimum seed rate, timely sowing and judicious application of irrigation, fertilizer and other inputs.

Wheat is the cereal of the temperate regions but is grown at high altitudes in the tropics and also extends into the tropical low lands. Wheat production is concentrated between latitudes 30-60°N and 27-40°S (Nuttonson, 1955). The climate of Bangladesh is favourable for wheat production during rabi season. This is because the optimum temperature for the growth of this crop is 10-20°C (Fisher, 1981) which eventually prevails in Bangladesh. Wheat can be grown in regions where annual precipitation ranges from 25-175 cm; about three-fourths of the land area based for wheat production receives an average of 37.5-87.5 cm annually (Briggle and Curtis, 1987). In the tropical climates, irrigation is necessary to produce good yields of wheat when precipitation is less than 20 cm during crop growth. Wheat can be grown on a variety of soils but reasonable drainage and good water holding capacity are preferred. In terms of soil pH, wheat is considered medium acid tolerant (Adams, 1981), but according to Doll (1964), the soil pH range for wheat is 5.5 to 7.0.

Among the factors responsible for low grain yield of wheat, different factors such as lack of irrigation water and plant nutrient, weed competition, insect attack, disease infection etc. are the most important. About 30% of wheat production is lost due to lack of irrigation water and 40% yield loss due to lack of nutrient supply in the country (Karim and Siddique, 2001). Integrated irrigation and fertilizer management are of great importance for achieving optimum and sustainable yields of wheat. Fertilizer use efficiency is closely related to soil moisture content. Fertilizers are not readily available to plants due to deficit soil moisture. In Bangladesh conditions, three to four irrigations are required for optimum wheat yield whereas farmers provide only one to two irrigations. In general, farmers apply medium to higher doses of fertilizer with less irrigation water compared to its requirement. This causes

low yield due to less availability of water as well as fertilizers to the plants (Rashid *et al.*, 2001). Soil water status has a direct relationship with the availability and uptake of nutrients by plants as water is integral component of soil solution, and is involved in transportation of nutrient elements. Wheat roots have positive and significant association with the uptake of nutrients (Islam *et al.*, 2006). However, enough irrigation water and nutrient supply can increase yield up to 70% in our country (Ahmed, 2006). Food production in Bangladesh is not increasing by keeping pace with the increase of population growth. Total land area under food production has been decreasing year after year to accommodate the ever-increasing population.

Wheat is mostly grown under rain fed conditions. Rain fed crop frequently suffers from drought resulting in significant growth and yield loss and decreased revenue with periodic drought affecting 50 and 70% of wheat-growing areas in developing and developed countries, respectively (Trethowan and Pfeiffer, 1999). The climate and soil of Bangladesh are quite favorable for the cultivation of wheat during robi season. Supplement irrigation given to wheat improves the development of grain as well as yield (Singh and Singh, 2005). Irrigation frequency has a significant influence on the growth and yield of wheat. With the increase of irrigation frequencies the grain yield of wheat can be increased (Khajanji and Swivedi, 2007). In Bangladesh, the rainfall during Rabi season is characteristically scanty and uncertain. As such, wheat gives poor yield under non-irrigated (rain fed) condition.

Wheat is a strategic crop and it is highly responsive to irrigation water during the short winter season between November and March. Application of only one irrigation increase the yield of wheat by more than 40%, whereas two to three irrigations with proper water and fertilizer management practices increase wheat yield by 50-100% (Hossain *et al.*, 2006). Water should be utilized for optimum and economic yield. Modern high yielding crop practices system can be sustained only with good water control and management at the farm level. Optimum water availability to plants during their growth is essential for realizing the full yield production. Every year crop production is essential to increase due to more and more efficient utilization of water through better management practices (Sarker *et al.*, 2007). Only about 42.78 percent of total wheat is growing land of Bangladesh under irrigation facilities and rest of remaining under rain-fed condition (BBS, 1998). Drought occurs almost every year due to scarcity of rainfall in dry season, which adversely affects the growth and yield of wheat. The growth and yield loss due to drought could be minimized by providing irrigation at least during the critical stage of growth, (Islam *et al.*, 2000). Insufficient water affects the germination of seed

and uptake of nutrients from soil. Moreover movement of nutrients through the plant body by physiological activities is also associated with soil water (Tisdale *et al.*, 1985). Sensitivity to moisture stress at different growth stages of wheat, however, varies widely. Singh (1981) found that booting or heading was the most sensitive stage to affect wheat yield for moisture stress. On the other hand, crown root initiation (CRI) stage of wheat was determined by the BARI scientists to be the most sensitive growth stage producing the highest seed yield with one irrigation (BARI, 1990). Crown root initiation in wheat was the most critical stage for irrigation and water shortage at this stage reduced the grain yield by 27% (Mahmood and Ahmad, 2005). Number of tillers improved with irrigation at Crown root stage and better grain yield was recorded with irrigation at crown root and boot stage (Mangan *et al.*, 2008). In case of adequate water supply, three irrigations given each at three defined growth stages viz., CRI, maximum tillering and grain filling stages significantly increased seed yield (BARI, 1986). Improper scheduling of irrigation results not only in wastage of water but also decreases the crop growth and yield. Irrigation schedules based on physiological stages have already been worked out for timely sown crop under different situations.

Nitrogen for wheat production is equally important to realize the yield potential. For maximization of crop yield, the use of fertilizers is very important. Among the different plant nutrients; nitrogen has the more effectiveness on growth which has the great role on higher grain yield and quality seed production (Ashok and Sharma, 2004). The effect of nitrogen is more prominent and significant over other fertilizers, as because nitrogen is the integral part of protoplasm, protein and chlorophyll and results in larger cell size and in turn increases plant height and crop yields (Hutchinson and Talbot, 1983). Nitrogen the major essential plant nutrient plays an important role in producing higher grain yield of wheat (Ahmed and Hossain, 2002). For increasing nitrogen use efficiency, top dressing and split application of nitrogenous fertilizers at critical growth stages of wheat are now being emphasized (Singh, 2003). Randhawa *et al.* (2004) also mentioned that the split application of nitrogenous fertilizers for wheat was more beneficial than its single dose application at sowing.

Added N fertilizers are subject to various losses in the soil mainly due to leaching, surface run off, volatilization and denitrification. Nitrogen loss through denitrification is the most serious problem and ranges from 25 to 90%. Nitrogen loss as ammonia volatilization ranges from 0 to 60% of applied nitrogen. It is estimated that only about 35% of the added nitrogen is recovered by the crop. However, the loss with split application of nitrogen could be reduced from 11 to 33% compared with 45 to 60% loss with basal application. The method of

nitrogen application also has a significant effect on the utilization of nitrogen. Generally, the nitrogen utilization rate is much higher in top dressing than the basal application. The efficiency of nitrogenous fertilizers can be increased by applying through splitting the total nitrogen fertilizer dose into a basal application and one or more top dressing. Split application of nitrogen is considered better than single application in increasing yield (Gravelle *et al.*, 1988).

To expand wheat cultivation and to sustain wheat yield during limited rainfall and to develop a suitable nitrogen fertilizer application package the present investigation will be carried out with the following objectives-

1. To evaluate the growth, phenology, yield and yield attributes of wheat under different soil moisture status and nitrogen management practices.
2. To study the effect of irrigation and nitrogen fertilizer management on flag leaf biochemical characters, nitrogen uptake, nitrogen use efficiency and water use indices of wheat.
3. To assess the agro-economic performance of the test wheat varieties under different irrigation and nitrogen fertilizer management.

CHAPTER 2

REVIEW OF LITERATURE

In Bangladesh, wheat is grown during rabi (winter) season and it is dry and as such, the inadequate soil moisture limits the use of fertilizers, and consequently results in decreased grain yield. An attempt has been made in this chapter to present a brief review of research in relation to growth and yield of wheat as influenced by time of irrigation and split application of nitrogen. It is an established fact that balanced fertilization especially nitrogen which is the most important plant nutrient and water management increases crop growth and gives higher yield. Some of the pertinent findings of the research with time of irrigation and split application of nitrogen on the growth and yield of wheat are reviewed in this chapter.

2.1. Effect of irrigation

Many experiments have been conducted on the effect of time of irrigation on the growth, yield and yield contributing characters of wheat in different wheat growing countries of the world. Some of the results of those experiments were reviewed below:

Simane *et al.* (1993) noticed that pre-anthesis moisture stress delayed phenological development whereas post-anthesis moisture stress accelerated it. They conducted a greenhouse experiment to study the response of 5 durum wheat cultivars to moisture stress at different development phases. Phenology, total dry matter (TDM), relative growth rate (RGR), leaf area ratio (LAR), net assimilation rate (NAR), leaf weight ratio (LWR), specific leaf area (SLA) were compared. TDM accumulation rate differed between the drought resistant and susceptible cultivars. RGR and its components changed with age and moisture availability. Drought resistant cultivars had a higher RGR in favourable periods of the growing season and a low RGR during moisture stress. In contrast, the drought susceptible cultivars showed an opposite trend. LAR explained the differences in RGR best, whereas the relationship between NAR and RGR was not significant. Even though both LWR and SLA were important factors determining the potential growth rate, LWR was of major importance to describe cultivar differences in LAR and consequently in RGR. They concluded that biomass allocation was the major factor explaining variation in RGR.

Sharma (1993) obtained higher yield with three irrigations given at crown root initiation, tillering and milking stages of wheat than other treatments with three irrigations. They also

found maximum water use efficiency with three irrigations given at CRI, tillering and milking stages.

Saha and Paul (1995) studied the effect of soil moisture on the growth parameters such as RGR, NAR, LAR, relative leaf growth rate (RLGR) and LWR of five wheat cultivars. LAR, RLGR and LWR were increased but NAR was decreased and RGR was unaffected by soil moisture. All the growth parameters decreased with plant age except NAR and RLGR which increased at the later stage of growth. They further reported the increase of grain yield due to soil moisture was not related to growth parameters.

Islam (1996) observed that irrigation significantly influenced the plant heights, number of effective tillers per plant, grain and straw yields but it had no influence of grains per ear and 1000-grain weight. The highest grain yield (3.71 t ha^{-1}) was obtained with three irrigations (25, 45 and 60 DAS) and the lowest with no irrigations (2.61 t ha^{-1}) was obtained.

Rahman and Paul (1996) stated that the irrigated wheat plants had higher panicle weight than the rainfed plants at all the stages of growth but significant effect was observed at 14 days after anthesis (DAA) in Akbar and 7 and 28 DAA in Barkat. The irrigated wheat plants had higher grain weight than the rain-fed plants.

Lalonde *et al.* (1997) reported that Irrigation effects on relative growth rate (RGR) of grain. The reason for higher prematurity of grains in the I_0 plants might be due to the water shortage during the three or four weeks after flowering and water stress along with high temperature at the grain developing stages resulted in decreasing RGR of grain.

Cooper (1998) reported that harvest index increases with increase in irrigation frequencies.

Boogaard *et al.* (1999) carried out an experiment in a Mediterranean environment in North Syria with wheat under rain-fed and irrigated conditions and reported that under rain-fed conditions harvest index was increased.

Sarker *et al.* (1999) stated that the rain-fed plants had consistently lower RLWC. The RLWC values of the irrigated plants were significantly higher in the morning but lower values were found at noon, showing some recovery in the afternoon.

BARI (2000) recorded maximum straw yields with three irrigations applied at CRI, maximum tillering and grain filling stages of crop. Irrigations given at CRI+ maximum tillering (MT), CRI+ Booting (BT) and CRI+grain filling (GR) were at par in respect of

number of spikes m^{-2} and grains spike $^{-1}$, but had highest spikes and grains over CRI+MT stages.

Hefni *et al.* (2000) reported that irrigation plays a positive role in increasing the number of tillers, ear plant $^{-1}$ and grain of wheat. Ear length and number of grains reduced significantly if irrigation is stopped at tillering and booting stages of wheat.

Islam *et al.* (2000) reported that the highest number of effective tillers plant $^{-1}$ (3.6) was obtained at control with no irrigation. The highest spike length (9.39) was found at two irrigation treatment.

Gupta *et al.* (2001) reported that grain yield and biological yield decreased to a greater extent when water stress was imposed at the anthesis stage while imposition of water stress at booting stage caused a greater reduction in plant height and number of tillers. Among the yield attributes plant height and number of tillers were positively correlated with grain and biological yield irrigation at the anthesis stage. Leaf area and shoot dry weight also significantly correlated with grain and biological yield at both the stages.

Razi-us Shams (2001) observed that the effect of irrigation treatments on yield and yield contributing characters were statistically significant. When irrigation frequency was increased the grain and straw yields, number of tillers, panicle length, number of grains panicle $^{-1}$ were gradually increased over control.

Singh and Singh (2001) reported that growth of wheat was poor when crop was grown under rain-fed condition. Under this condition tiller number, panicle length, grain number and 1000-grain weight were lower.

Yadav *et al.* (2001) reported that two irrigations scheduled at CRI and milking stages gave the maximum number of grains spike $^{-1}$ (65) of wheat, which was found to be at par with those at one irrigation.

Mandal *et al.*,(2002) conducted a field experiment in India during 1984-86 and 1986-87 on wheat with 2 levels of irrigation: one at crown root initiation (CRI) and at CRI + booting stages and reported that LAI increased significantly with increasing levels of irrigation.

Paul *et al.* (2002) conducted a field study at Rajshahi, Bangladesh on eight cultivars of *Triticum aestivum* L. They showed that irrigated plants had higher RLWC and chlorophyll content but lower proline and sugar as compared to rain-fed plants.

El-Zahab *et al.* (2003) stated that RGR increased steadily during early growth stage and then decreases slowly.

Ghosh *et al.* (2003) in Kalyani, West Bengal carried out experiment on wheat grown as pure and intercropping system and observed that without irrigation, with irrigation at 21 and 65 DAS and with irrigation at four critical growth stages crop gave grain yields of 2.08 t ha⁻¹, 2.99 t ha⁻¹, 3.40 t ha⁻¹ respectively.

Haider and Paul (2003) studied physio-biochemical responses of four bread wheat cultivars under three different water regimes in field condition over two rabi seasons. Water stress decreased RLWC and chlorophyll a and b contents but increased chlorophyll a : b ratio. Increased proline and sugar content in the leaves of all the four cultivars were noticed when plants experienced water stress.

Grain and straw yields and yield contributing characters gradually increased with increasing number of irrigation (Islam, 2003). The highest grain and straw yields, the maximum plant height, the highest number of effective tillers, and the maximum number of grains spike⁻¹ were obtained by three irrigations (I₄) applied at 25, 50 and 70 days after sowing. The increased grain and straw yields in I₄ treatment over control was 60.7% and 59.4% with irrigation.

Upadhyaya and Dubey (2003) performed a field experiment on wheat where 3 irrigation frequencies viz. (a) one irrigation at CRI stage, (b) two irrigation one each at CRI and booting stages and (c) four irrigations one each at crown root initiation (CRI), booting, flowering and milking stage were included. They observed that grain yield varied significantly with irrigation frequencies. Four irrigations performed the maximum grain yield which was significantly greater than one or two irrigations.

An Experiment was carried out by Jana and Mitra (2004) on wheat cv. Sonalika giving irrigation at crown root initiation, tillering, flowering and dough stages. They found that irrigation increased plant height, number of effective tillers, ear plant⁻¹ and grain and straw yields.

Twenty bread wheat cultivars were subjected to irrigation at 10, 20 and 30-day intervals in a field experiment conducted by Zarea and Ghodsi (2004) in Iran and found that number of spike/m², 1000-kernel weight, grain yield and harvest index decreased with increasing irrigation intervals. When a 20 and 30-day irrigation interval were applied, number of spike/m², grain yield and harvest index were higher in cultivars C-75-14 and C-75-9.

Abdorrahamani *et al.* (2005) reported that crop growth rate, relative growth rate, dry matter accumulation per unit area, number of ears per unit area, number of grains per ear, 1000-grain weight, biological yield, grain yield, harvest index, plant height and productivity were evaluated. Drought stress reduced dry matter production, crop growth rate and relative growth rate. Green cover percentage, crop growth rate, and relative growth rate did not significantly vary among the cultivars. All traits except the number of grains per ear and harvest index were affected by water deficit.

Sher and Parvender (2006) carried out a field experiment during winter on sandy loam soils in haryana, India, to evaluate the effects of irrigation regimes (IW/CPE 0.5, 0.7 and 0.9) on growth, yield and nutrient uptake of wheat under late-sown conditions. The irrigation level IW/CPE 0.9 (4 irrigations) being statistically at par with IW/CPE 0.7 (3 irrigations) produced significantly higher plant height, number of tillers/m², 1000-grain weight and straw yield than IW/CPE 0.5 (2 irrigations), which was at par with 3 irrigations. The irrigation regime IW/CPE 0.9 recorded significantly higher dry matter accumulation, grains per spike and grain yield than IW/CPE 0.7 and 0.5. N, P and K uptake by both grain and straw also increased progressively with increasing number of irrigations.

Ali and Amin (2007) conducted a study to determine the effect of irrigation frequencies on the yield and yield attributes of the wheat cultivar Shatabdi. Irrigation treatments were given as: no irrigation, control (T₀); one irrigation at 21 DAS (T₁); two irrigations at 21 and 45 DAS (T₂); three irrigations at 21, 45 and 60 DAS (T₃); and four irrigation at 21, 45, 60 and 75 DAS (T₄). Significant effects were observed on plant height, number of effective tillers per hill, spike length, number of spikelets per spike, filled grains per spike due to different levels of irrigation. Two irrigations at 21 and 45 DAS significantly enhanced the growth, yield attributes and yield of wheat over the other treatments. Results also showed that grain yield, straw yield and harvest index were significantly higher at T₂ compared to the other treatments of the study.

Mohammad *et al.* (2007) reported that effect of irrigation schedule on number of tiller per plant further analysis by using DMRT test shows that plots irrigated at three weeks interval had highest number of tillers (17.66) and it was significantly different from plots irrigated after four, five and six weeks interval, respectively. It is clear from the results that abundant moisture favored increased tillering that is why lowest number of tillers was recorded from plots irrigated at six week interval.

Pal and Upasani (2007) conducted a field experiment in India to determine the effects of irrigation on the growth and yield of wheat cv. HD 2285. The treatments comprised different irrigation frequency (2, 3 or 4 times) carried out during critical growth stages (crown-root initiation, highest tillering, booting and milking). Wheat plants which received 4 irrigations at the crown root initiation, highest tillering, booting and milking stages recorded the highest yield.

Kong *et al.* (2008) carried out an experiment in India to study the effect of irrigation on the yield of wheat and water use efficiency under limited irrigation. The irrigation treatments designed were: no irrigation (control); 30 mm of irrigation norm at elongation and booting stage; 45 mm at elongation and booting stage; 30 mm at filling stage; 45 mm at filling stage; 30 mm at elongation and 30 mm at filling stage; and 45 mm at elongation and booting stages and 45 mm at the filling stage. Irrigation increased the average yield of wheat by 13.0-39.6% and the water use efficiency by 7.0-18.0%. The number of ears of winter wheat could be increased by irrigation during the elongation and booting stages and the water use efficiency could also be improved. Irrigation at filling stage improved the 1000-grain weight and water use efficiency of wheat. It is concluded that the best time for limited irrigation is the elongation and booting stages.

The study was carried out by Mangan *et al.* (2008) to evaluate the performance of yield and yield components traits of wheat genotypes under water stress conditions. Four wheat varieties were screened under water stress conditions at Nuclear Institute of Agriculture (NIA) Tandojam. Different irrigation treatments (1, 2, 3 and 4) were applied during various crop growth stages. Grain yield and yield contributing traits of wheat varieties were significantly affected under water stress conditions. 1000-grain weight, main spike yield and grains spike⁻¹ and grain yield were higher in four irrigations compared to other irrigation treatments.

Bhattacharje (2009) conducted an experiment to study the effect of irrigation on growth and yield of different wheat varieties. The treatments comprised (A) three irrigation levels (i) no irrigation i.e. control, (ii) one irrigation given at crown root initiation (CRI) stage, (iii) two irrigations given at CRI and another at grain filling stage and (B) four varieties (V_1 = Bijoy, V_2 = Prodig, V_3 = Sufi and V_4 = BAW1064). It was observed that the highest dry weight per plant was obtained with two irrigations. Whereas, significantly the lowest values of were obtained from no irrigation.

Wang *et al.* (2009) to investigate the effects of different irrigation and N supply levels on spring wheat growth characteristics, water consumption and grain yield on recently reclaimed sandy farmlands with an accurate management system with irrigation regimes. Water consumption was increased with irrigation; water consumption in high irrigation treatment was increased by 16.68% and 36.88% compared with intermediate irrigation treatment and low irrigation treatment, respectively. The low irrigation (378 mm), accompanied by 221 kg N/hm² was the best management system for the relative high economic yield and high WUE in this region.

A field experiment was conducted by Li *et al.* (2010) to investigate the leaf area index, dry matter accumulation, photosynthetic characteristics and yield of winter wheat under different irrigation stages and amounts. The results showed that, before the jointing stage, the leaf area index and spike length increased with the increase of irrigation amount. After jointing stage, all the indexes were good when the field water capacity maintained at 65%, while too much irrigation amount was unfavourable to the dry matter accumulation, especially to the photosynthetic rate of flag leaf and yield formation after anthesis.

Field experiment was conducted by Mishra and Padmakar (2010) to study the effect of irrigation frequencies on yield and water use efficiency of wheat varieties. The I₂ treatment combinations comprised of four irrigation levels viz., I₁ (one irrigation at CRI stage), I₂ (two irrigations: one each at CRI and flowering stages), I₃ (three irrigations: one each at CRI, LT and flowering stages) and I₄ (four irrigations: one each at CRI + LT + LJ + ear head formation stages) along with the combination of three varieties. Progressive increase in number of irrigations from 1 to 4 increased various grain yield and yield contributing characters viz., effective tillers m⁻², ear length, no. of grains ear⁻¹ and test weight while three and four irrigations were found statistically at par with each other. The highest grain yield (40.65 q ha⁻¹) was credited to I₄ that was significantly superior over I₁ and I₂ but non-significant with I₃.

Naeem *et al.* (2010) conducted a field study pertaining to the effect of different levels of irrigation on yield and yield components of wheat cultivars. Treatments were three cultivars and five irrigation levels I₁ (irrigation at crown root stage), I₂ (irrigation at crown root + tillering), I₃ (irrigation at crown root + tillering + booting), I₄ (irrigation at crown root + tillering + booting + anthesis), and I₅ (irrigation at crown root + tillering + booting + anthesis + milking). Wheat crop supplied with five irrigations at crown root + tillering + booting +

earring + milking recorded the highest grain yield (5696.8 kg ha⁻¹) which was significantly higher than all the other irrigation levels.

El-Tahir *et al.* (2011) reported high dry matter production is an important pre-requisite for high growth of plant. In his study he observed that dry matter accumulation was sensitive to water deficit, it was consistently reduced under water stress. The simple linear relationship between dry matter production and radiation interception break down when water is in short supply. In both seasons dry matter accumulation was consistently greater with shorter irrigation intervals (7, 10 and 14 days) than the longer ones (21 and 28 days).

Ghulam (2011) conducted an field experiment with irrigated 5 times in wheat, significantly had maximum tillers, spike length, grains spike⁻¹, grain weight spike⁻¹, seed index, biological yield, grain yield, harvest index, dry matter, leaf area index, crop growth rate, relative crop growth rate, N uptake, P uptake and K uptake. Application of 5 irrigations also recorded early maturity, higher relative growth rate. Further increase in irrigation frequency had non-significant response on these crop traits.

Islam *et al.* (2011) conducted an experiment to observe the effects of tillage and irrigation on the growth and yield of wheat (cv. Shatabdi). The irrigation treatments were I₀ = no irrigation, I₁ = one irrigation, I₂ = two irrigation and I₃ = three irrigation. In case of irrigation practices, the tallest plant (86.57 cm) was found in I₃ and the shortest plant (74.53 cm) was found under the treatment I₀.

Karim (2011) reported that crop growth rate (CGR) for the varieties was slower during early vegetative phase of the crop due to lower temperature; thereafter it increased sharply. Moisture stress at different crop growth stages affected CGR differently. Fully irrigated crops (T₀) indicated significantly greater CGR than other crops throughout the season.

The effect of compensation irrigation on the yield and water use efficiency of winter wheat in Henan province was studied by Wu *et al.* (2011) and found that the effect of irrigation on plant height, the combinative treatment of irrigation in the former stage and medium irrigation compensation in the latter were better. The wheat yield was increased by 2.54%-13.61% compared to control and the treatments, irrigation of 900 m³ ha⁻¹ at the elongation stage and of 450 m³ ha⁻¹ at the booting stage or separate irrigation of 900 m³ ha⁻¹ at the two stage were the highest.

Wang *et al.* (2012) conducted a field experiment to investigate the effects of different irrigation on grain yield, water use efficiency (WUE). Significant irrigation effect was

observed on grain yield, kernel numbers and straw yield. The highest levels were achieved with a high irrigation supply, although WUE generally decreased linearly with increasing irrigation rates. The low irrigation treatment produced significantly lower grain yield (20.7 %), kernels number (9.3 %) and straw yield (12.2 %) than high irrigation treatment. The low irrigation treatment had a higher WUE ($4.25 \text{ kg ha}^{-1} \text{ mm}^{-1}$) than that of $3.25 \text{ kg ha}^{-1} \text{ mm}^{-1}$ with high irrigation.

Dong *et al.* (2013) was conducted a field experiment to study the effects of different irrigation and planting modes on the water consumption characteristics and dry matter accumulation and distribution of winter wheat. Three planting patterns (uniform row, wide-narrow row, and furrow) and four irrigation schedules (no irrigation, W_0 ; irrigation at jointing stage, W_1 ; irrigation at jointing and anthesis stages, W_2 ; and irrigation at jointing, anthesis, and milking stages, W_3 ; with 60 mm per irrigation) were installed. With increasing amount of irrigation, the total water consumption increased, while the soil water consumption and its ratio to total water consumption decreased significantly. As compared with W_0 , the other three irrigation schedules had a higher dry matter accumulation after anthesis and a higher grain yield, but a lower water use efficiency (WUE).

Sarker *et al.* (2013) conducted an experiment to investigated the effects of number and timing of irrigation application on yields and reported that grain yield (GY), biomass, harvest index (HI), 1000-grain weight, grains/spike and spike length and water productivity (WP) were affected by deficit irrigation. During grain formation stage, water deficit did not affect the grain yield but saved water significantly. Such water deficit treatments also shortened the grain maturation period. The highest water productivity (2.02 kg/m^3) was observed in treatment which was irrigated only once at crown root initiation stage (T_2) although the yield was comparatively low. The CRI (crown root initiation) stage was found the most sensitive to water stress. Water stress at vegetative stage also reduced the yield considerably.

Abderrazzak *et al.* (2013) conducted an experiment to determinate the optimal growth stage for applying supplemental irrigation to enhance bread wheat (*Triticum aestivum* L.) productivity and water use efficiency under rain-fed condition with three water treatments (I); rain-fed (I_0), irrigated (60 mm) at 21 according (I_1) and irrigated (60 mm) at 59 (I_2). They showed that I_2 improves water use efficiency, grain yield and its components by 91 and 60% respectively, compared to I_0 and I_1 treatments.

Atikullah *et al.* (2014) conducted a field experiment to find out the consequence of irrigation levels on growth, yield attributes and yield of wheat (BARI Gom-26). Four different irrigation levels (viz. I₀: No irrigation i.e. control; I₁: Irrigation at 20 DAS at crown root initiation stage; I₂: Irrigation at 55 DAS at flowering stage and I₃: Irrigation at 75 DAS at grain filling stage) were used. They reported that maximum dry matter content (18.8 g plant⁻¹), crop growth rate (CGR) (13.5 g m⁻² day⁻¹), relative growth rate (RGR) (0.024 g m⁻² day⁻¹) were found from I₁ which was statistically identical with I₂ whereas minimum from I₀. Plant height (80.7 cm), number of tiller (4.9 hill⁻¹), number of spike (4.7 hill⁻¹), number of spikelets (18.5 spike⁻¹), spike length (19.2 cm), filled grains (29.3 spike⁻¹), total grains (31.3 spike⁻¹), 1000-grains weight (44.4 g), yield (grain 3.4 t ha⁻¹, straw 5.7 t ha⁻¹ and biological 9.1 t ha⁻¹) and harvest index were correspondingly showed higher results as of growth characters.

Sana Ullah Baloch *et al.* (2014) conducted a field experiment to investigate the effect of different irrigation schedules on growth and yield Performance of wheat varieties and reported that the wheat crop irrigated five times resulted maximum plant height (86.206 cm), tillers m⁻² (402.11), spike length (12.040 cm) spikelet's spike⁻¹ (18.979), grains spike⁻¹ (47.099), seed index (44.580 g), biological yield, (13732 kg ha⁻¹), grain yield (6999.30 kg ha⁻¹) and harvest index (50.95%) as compared to four irrigations and three irrigations.

2.2. Effect of nitrogen

Nitrogen is an essential nutrient for plants. Urea is used as a common source of nitrogen fertilizer. The rate and split application of nitrogen have remarkable influence on the growth, yield and yield contributing characters of wheat. Different researcher reported the effect of urea on yield contributing component and grain yield. Some available information and literature related to the effect of source of nitrogen on the growth and yield of wheat are discussed below:

Garmashov *et al.* (1985) stated that grain protein content could be increased by split application of nitrogen at flowering stage though it did not increase grain yield.

Protein content in wheat can be manipulated to some extent by the amount of fertilizer applied and the timing of application. Applying nitrogen to the soil early during crop development will generally result in high grain yield and applying nitrogen at flowering time or a little effect upon yield (Dampney and Salmon, 1990).

Grignani and Reyneri (1990) found that grain protein content was higher with the later than earlier nitrogen application and increased with increase in nitrogen rate.

Ball *et al.* (1991) conducted a two-year study during 1983-85 with 2 wheat varieties and 4 levels of nitrogen (0, 40, 80 and 120 kg ha⁻¹). Nitrogen was applied in split as half at sowing and the remaining half as top-dressed. Grain yields increased in both the years with 120 kg N ha⁻¹ with the rate recording 10.4 and 11% higher protein content than no N treatments during the 1983-84 and 1984-85 seasons, respectively.

Splitting the nitrogen application increases flour protein content and bread loaf volume according to Ayoub *et al.* (1994).

Phiri and Mwale (1995) suggested that a continuous and adequate supply of nitrogen which can be achieved by split applications of the top dressing fertilizer. The first done may be applied at about 6 weeks (full tiller stage) and the second at anthesis. The proportion of split application of top dressing should be about 75% of the recommended rate as the first and 25% as the second dose at anthesis for higher protein content.

Dighe *et al.* (1996) conducted an experiment where N fertilizer was applied in splits in 2 treatments as follows: 50% N as basal +50% N at CRI or 10% N as basal + 60% N at CRI + 30% N at late jointing. They found that available N was observed to be lost when a high initial N was applied at sowing. Splitting the applied N (10% N + 60% N + 30% N at sowing, CRI and late jointing, respectively) resulted in a reduced loss of N in the initial stages of growth giving higher yield.

Hossain *et al.* (1996) reported that grain yield was increased significantly by fertilizer. Highest grain yield was obtained by 120 N: 60 K kg ha⁻¹, the yield of grain was being 3.72 t ha⁻¹. They also reported that straw yield increased significantly by fertilizer. Straw yield was 5.18 t ha⁻¹ at N 160: P 100: K 80 kg ha⁻¹.

Sarker *et al.* (1996) found that the application of 60 or 120 kg N ha⁻¹ to wheat at sowing or in two split dressings at sowing and before or after the first irrigation gave grain yields of 1.16 – 1.17 and 1.32 – 1.49 t ha⁻¹, respectively compared with 0.26 ton without N. The date of N application had no significant effect on yields.

Upadhyay and Tiwari (1996) conducted a field experiment and reported that nitrogen application up to 120 kg N ha⁻¹ increased effective tillers m⁻¹, spike number plant⁻¹, spike length, fertile spikelets spike⁻¹ compared with lower dose (90 kg N ha⁻¹). Application of N beyond 120 kg N ha⁻¹ did not increase the value of these characters. They also found that the effect of N on seed yield was significantly greater at 120 kg N ha⁻¹ (27.7 q ha⁻¹) compared with 90 kg N ha⁻¹ (25.2 q ha⁻¹) but was at par with 150 kg N ha⁻¹ (27.2 q ha⁻¹).

Singh *et al.* (1997) reported that total tillers hill⁻¹ increased with the increase of N levels and the highest number of total number of tillers hill⁻¹ was obtained at 120 kg N ha⁻¹.

Crop growth rate (CGR) is the rate of dry matter production per unit area of land per unit time and it is a simple and important index of agricultural productivity (Hunt, 1999).

Kumar and Sharma (1999) conducted a field experiment and observed that dry matter accumulation in wheat increased significantly when the rate of N application increased from 0 to 40 kg N ha⁻¹ at 40 DAS, 0 to 120 kg N ha⁻¹ at 60 DAS, 0 to 80 kg N ha⁻¹ at 80 DAS. Nitrogen application also hastened the growth and resulted in higher percentage of total dry matter accumulation in early stage of crop growth.

Haloi and Baldev (2000) observed higher RGR at initial stage of crop growth.

Halvorson *et al.* (2000) carried out a field experiment with 3 doses of N (0, 22 and 45 kg N ha⁻¹). He found that increasing level of N gave significantly higher seed yield. Maximum seed yield was obtained at 45 kg N ha⁻¹.

Sushila and Giri (2000) set an experiment with different nitrogen doses (0, 45, 90 kg ha⁻¹) and observed that plant height, total tillers m⁻², spike length and 1000-grain weight significantly increased with the increasing doses of nitrogen.

Karim and Siddique (2001) reported that higher RGR was obtained at vegetative phase.

Mozumder (2001) performed an experiment to investigate the effect of different levels of nitrogen and seed rate on the yield and yield contributing characters of wheat. Treatments of nitrogen in that experiment were 0, 30, 60, 90 and 120 kg ha⁻¹. He reported that total tillers plant⁻¹, spike length, total filled grains spike⁻¹ and 1000-grain weight increased with increasing rate of nitrogen. The results indicated that the highest tillers plant⁻¹, spike length, total filled grains spike⁻¹ and 1000-grain weight were recorded when 120 kg N ha⁻¹ was applied.

Sarena and Jana (2001) concluded that application of nitrogen at 100 kg ha⁻¹ half nitrogen as basal plus half nitrogen just after first irrigation as top dressing recorded higher straw yields of wheat as compared to nitrogen top dressed.

Pandit *et al.* (2002) conducted two experiments of wheat and it was reported that the highest grain yield, biological yield, grain protein content (%), grain protein yield were obtained from three split application of nitrogen. Application of nitrogen in four splits, last splits applied after anthesis, did not show any improvement of grain yield and grain protein content (%).

Effect of split application of nitrogen on relationship of grain yield with grain protein yield was positive and significant.

Samra and Dhillon (2002) reported that application of nitrogen in two splits i.e. half at sowing and half at CRI stage remarkably improved the grain and straw yields of wheat on sandy loam soil at Ludhiana (Punjab) over all the other split application.

Sowinski and Kozak (2002) carried out an experiment to study the effect of N rate on the yield and quality of winter wheat. The treatments considered of 30, 60 or 90 kg N ha⁻¹. They found that seed yield increased by 7.5, 23.8 and 52.0% with application of nitrogen at 30, 60 and 90 kg ha⁻¹, respectively and the protein yield increased by 3.8 kg for each 1 kg of N applied.

Wagan *et al.* (2002) conducted to assess the effect of source and schedule of nitrogenous fertilizer on wheat growth and yield contributing characters where variety Sarsabz was drilled to test various nitrogenous fertilizers (urea, ammonium nitrite and ammonium sulphate) applied in two and three splits with basal dose of P and K. The results revealed that nitrogen applied in three split doses significantly increased plant height.

Das (2002) set up an experiment to evaluate the effect of planting density and rate of nitrogen application on the yield of wheat cv. Ranchan. He used four level of nitrogen (0, 40, 80 and 120 kg ha⁻¹) and found that spike length, fertile spikelets spike⁻¹, grain yield and straw yield increased gradually with the increase of nitrogen dose.

Das (2003) carried out an experiment to observe the effect of row spacing and nitrogen application on the growth and yield of wheat. The experiment consists of four-row spacing and four nitrogen levels. Results of that experiment showed that nitrogen had significant effect on plant height, total tillers, number of effective tillers and spike length. At growth stage the highest values of plant height, total tillers, number of effective tillers and spike length plant were obtained from the 180 kg N ha⁻¹.

Deshmukh *et al.* (2003) reported that nitrogen application in three splits at sowing, crown root initiation and jointing (1:2:1) produced higher number of effective tillers m⁻², spikelets ear⁻¹, 1000 grain weight and yield of grain and straw compared to other splits.

Frank and Bauer (2003) reported that terminal spikelet increased with increasing levels of nitrogen. Plant height of wheat is usually influenced remarkably with different levels of N application.

Kumar *et al.* (2003) conducted an experiment in India, to determine the effect of nitrogen application at 0, 50, 75, 100 and 150 kg ha⁻¹ on the chlorophyll content, dry biomass of whole plant and plant height of late-sown winter wheat cv. HD 2285. Plant heights were found positively correlated with nitrogen levels up to 125 kg ha⁻¹.

Ananda (2004) reported that among split application of nitrogen, nitrogen applied as half basal + one-fourth at 30 DAS + one-fourth at 60 DAS recorded higher wheat plant height, grain and straw yields as compared to nitrogen applied as half basal + half at 30 DAS.

Chanda and Gunri (2004) conducted an experiment to study the effect of N fertilizer (100, 125, 150, 175 and 200 kg ha⁻¹) on hybrid (Pratham 7050 and Pratham 7070) and high yielding (Sonalika) wheat genotypes. They reported that dry matter accumulation at all the stages increased with increasing levels of N up to 200 kg ha⁻¹.

Chandurkar *et al.* (2004) conducted a field experiment to determine the response of wheat to N content and uptake in grain and straw with increasing nitrogen fertilizer rates (90, 120 and 150 kg N ha⁻¹). The highest grain yield, nitrogen content, nitrogen uptake and protein content were obtained with 150 kg N ha⁻¹.

Knapowski and Ralcewicz (2004) conducted a field experiment to determine the influence of different rate of N (0, 80, 120 and 160 kg ha⁻¹) on grain yield and technological quality of two winter wheat cultivars (Begra and Korweta). An increase of grain yield of winter wheat was recorded with the application of N at 120 kg ha⁻¹.

Mazurkiewicz and Bojarczyk (2004) carried out an experiment to evaluate the effect of nitrogen fertilizer on yield of wheat. There were six levels of nitrogen viz. 0, 50, 100, 150, 200 and 250 kg ha⁻¹ in that experiment. They found that differentiation of the level of nitrogen fertilization did not significantly influence the mass of 1000-grain.

Pandey *et al.* (2004) conducted an experiment to study the effect of fertilizer levels and seed rate on growth and yield of surface-seeded wheat. They used 0, 60, 90, 120 and 150 kg N ha⁻¹ and observed that effective tillers per m², grain yields and straw yields differed significantly under varying fertilizer levels.

Ram *et al.* (2004) conducted a field trial to find out the effects of different N levels (0, 40, 80, 120 and 160 kg ha⁻¹) on the growth and yield of wheat. They observed that plant height increased with increasing rate of nitrogen.

Akter (2005) carried out an experiment to examine the effect of nitrogen levels under rain-fed and irrigated conditions on yield and seed quality of wheat. The experiment was involved with four nitrogen levels viz. 0 (control), 50, 100 and 150 kg ha⁻¹. She found progressive increased of plant height, number of total tillers plant⁻¹, effective tillers plant⁻¹, spike length, seed spike⁻¹, thousand seed weight, seed yield and straw yield with the increasing levels of nitrogen.

Cerny *et al.* (2005) conducted a field experiments to study the effects of different levels of nitrogen (N) fertilizer application. Grain yield and technological quality parameters were significantly influenced by fertilizer application. Isodur produced the highest grain yield (3.85 t ha⁻¹, increased by 4.37%) with the application of 80 kg N ha⁻¹. Martondur yielded the highest (3.96 t ha⁻¹, increased by 16%) at the rate of 120 kg N ha⁻¹ Istrodur achieved the highest protein content (13.66%) and glassiness (83.63%) at a rate of 120 kg N ha⁻¹ and the protein content and glassiness was 16.65 and 85.89%, respectively, for Martondur applied with 80 kg N ha⁻¹.

Ali *et al.* (2005) conducted an experiment in Multan, Pakistan with N at 0, 70, 140 and 210 kg ha⁻¹ were applied on wheat cultivars Inqlab-91 and Bakhar-2000. Bakhar-2000 produced more tillers and taller/plants than Inqlab-91. Plant height increased with increasing N rate. N at 210 kg ha⁻¹ produced the highest number of fertile tillers (569.75/m²), straw yield (9.05 t ha⁻¹) and grain yield (4.77 ton ha⁻¹). N application increased vegetative growth and biological yield.

Pasha (2005) reported that plant height was not vary significantly between two splits (one third N as basal + two third at first node stage) and three splits (half N as basal, one fourth N at tillering + one fourth N at tillering).

Rahman (2005) conducted an experiment including four levels of nitrogen viz. 75, 100, 125 and 150 kg N ha⁻¹. He reported that number of total tillers hill⁻¹, effective tillers hill⁻¹, length of spike, yield components and grain yield were significantly higher at 150 kg N ha⁻¹.

The effects of nitrogen (N) applications on winter wheat cultivars were studied in field trials conducted in a central Hungarian region by Szentpetery *et al.* (2005). Nitrogen fertilizer rates of 0, 40, 80, 120, 40+40 and 80+40 kg ha⁻¹ were applied at tillering and after anthesis (Feekes 3 and Feekes 10.5). The N fertilizer applied was ammonium nitrate in 34% cc. In the experiment, the changes of quantity of the yield were analyzed. N top dressing had a great importance. The 80 and 120 kg ha⁻¹ fertilizer doses were the most effective.

Yadav *et al.* (2005) carried out a field experiment during the winter seasons of 1999-2000 and 2000-2001 to assess the performance of zero tillage in wheat (*Triticum aestivum* L.) under varying levels of each successive increment of N 120 to 180 kg ha⁻¹. While grains yield increased significantly with 180 kg ha⁻¹. Effective tillers m⁻¹ row length increased by 29.3% with 180 kg ha⁻¹ over 120 kg ha⁻¹. Application of nitrogen up to 150 kg ha⁻¹ significantly increased the grain yield. The increase in grain yield was 12.3 and 17.3% with 150 and 180 kg ha⁻¹, respectively over 120 kg ha⁻¹.

Chaturvedi (2006) conducted a field experiment in India to evaluate the effects of different rates of nitrogen (0, 25, 50, 75, 100 and 125 kg ha⁻¹) applied as urea on the growth, yield, and nutrient uptake of wheat (*Triticum aestivum*) cv. Raj 3077. Various growth and yield parameters of the crop were influenced differently by various nitrogen rates. Nitrogen at 125 kg ha⁻¹ was optimum for the growth, yield and nutrient uptake of wheat. Application of 125 kg N ha⁻¹ significantly increased plant height (95.2 cm), total number of tillers (1402/m²), number of green leaves (1067/m²), dry matter accumulation (14.65 t ha⁻¹), number of grains per spike (40.5), 1000 grain-weight (48.1 g), grain and straw yields (4667 kg/ha based on pooled data), and uptake of N (102.3 kg ha⁻¹) respectively.

Raigar and Pareek (2006) carried out a field experiment in India to determine the yield and yield attributes of wheat as influenced by different levels of nitrogen and time of application. Application of nitrogen at 120 kg ha⁻¹ was significantly enhanced yield attributes, grain and straw yield of wheat. Application of nitrogen in three split (1/3 sowing + 1/3 CRI + 1/3 FN) significantly increased grain, straw yield and effective tillers/m row length whereas number of grain per ear, Ear length and test weight did not differ significantly due to time of application.

The performance of durum wheat cultivars PBW 34 supplied with 120, 150 and 180 kg N ha⁻¹ was evaluated in a field experiment conducted in India during the rabi season by Virender *et al.* (2006). Plant height, number of ears per head, 1000-grain weight, grain yield, straw yield, grain appearance score and hectolitre weight increased with increasing rates of N and highest with 180 kg N ha⁻¹.

Chandurkar *et al.* (2007) carried out a field experiment to determine the response of improved wheat cultivars and their N content and uptake in grain and straw with increasing N fertilizer rates (90, 120 and 150 kg N ha⁻¹). The highest grain yield, N content, N uptake and

protein content was obtained with 150 kg N ha⁻¹ treatments. GW-322 gave the highest grain yield, N content, total N uptake and protein content.

Oad *et al.* (2007) conducted a field experiment in Pakistan to assess the suitable nitrogen (N) levels and placements for the yield and yield traits of wheat cv Kiran-95. Three N levels (80, 120 and 150 kg ha⁻¹) were incorporated through broadcast, split, pop-up and foliar methods. Split application of 120 kg N ha⁻¹ significantly produced lengthy spikes, more grain number per spike, better seed index and maximum grain yield per hectare followed by broadcast, foliar and pop-up N placements.

Shen *et al.* (2007) conducted a field experiment in Jiangsu, China to identify the effects of N application rates (180 and 240 kg ha⁻¹ on grain yield, protein and its components in wheat. The grain number per spike increased with the increase of N application rate, while the 1000-grain weight decreased. The ear number per unit area, dry matter accumulation amount after flowering, leaf area index at heading stage and grain yield increased with the increase of N application rate. When the N rate was 180 kg ha⁻¹, the ear number could increase. The suitable amount of N rate for high yield and good quality in Ningyan 1 was 180 kg N ha⁻¹ and 240 kg N ha⁻¹ respectively.

Xiang *et al.* (2007) carried out a field experiment to study the effects of N application rates (180 and 240 kg ha⁻¹) and basic seedling number (90, 180, 270 and 360 × 104 ha⁻¹) on grain yield in wheat. They found increased leaf area index, dry matter accumulation, effective tillers and grain yield after flowering with the increase of nitrogen application.

Liaqat *et al.* (2008) conducted an experiment to evaluate the response of wheat cv. Uqab-2000 to N at 84, 128, 150, 175 and 200 kg ha⁻¹. The number of productive tillers per m² (408), 1000-grain weight (41.2 g) and crop yield (5160 kg ha⁻¹) were highest at a rate of 150 kg N ha⁻¹. N at 175 kg ha⁻¹ resulted in the highest number of grains per spike. Maximum plant height was obtained at N at 200 kg ha⁻¹. The effects of mineral N fertilizer (at 30, 60, 90 and 120 kg ha⁻¹) on the leaf area, dry matter content of the aboveground part of 100 plants, number of spikelets in the spikes of the main and secondary stems, and the relation of these indices to grain yield of winter wheat.

Hira (2009) observed significant variation due to various level of nitrogen application. She found that the highest harvest index (36.73%) was observed in 115 kg N ha⁻¹ and lowest harvest index (34.56%) observed in the case of 161 kg N ha⁻¹.

Sultana (2009) found significant influence of nitrogen level on the harvest index of wheat. She observed that the highest (41.40%) harvest index in the treatment of 115 kg N ha⁻¹ and lowest (35.38) harvest index in the treatment of 0 kg N ha⁻¹.

Rehman *et al.* (2010) found that the tillers m⁻² increased linearly with the increase in NPK levels and maximum tillers m⁻² (330) were noted at 80-60-60 kg NPK ha⁻¹.

Saleem *et al.* (2010) find out that the leaf area indices continued to increase up to the highest application rate (200 kg N ha⁻¹).

Mattas *et al.* (2011) studied the effect of increasing levels of nitrogen fertilization and its time of application on the growth, yield and N uptake of durum wheat. Three levels of N (120, 150 and 180 kg ha⁻¹) was given in main plots whereas the three times of nitrogen application: 1/2 at sowing + 1/2 at CRI, 1/3 at sowing + 1/3 at CRI + 1/3 at boot stage and 1/3 at sowing + 1/3 at CRI stage + 1/3 at anthesis stage were given in the subplots. Increasing level of nitrogen significantly increased the number of tillers and number of effective tillers.

Wang *et al.* (2012) conducted a field experiment to investigate the effects of different N application rates on grain yield, water use efficiency (WUE). N fertilizer was applied with five levels of 0, 79, 140, 221 and 300 kg N ha⁻¹. They found that N application rate of 221 kg ha⁻¹ had the highest values of grain yield, kernel numbers, straw yield and WUE.

Abderrazzak *et al.* (2013) conducted an experiment to determinate the optimal growth stage for applying supplemental nitrogen to enhance bread wheat (*Triticum aestivum* L.) productivity and water use efficiency under rainfed condition. Nitrogen fertilizer was applied with five nitrogen doses (N); 0, 40, 80, 120 and 160 kg N ha⁻¹. Grain yield and other yield components increased simultaneously with the increase in nitrogen inputs. The 120 kg N ha⁻¹ dose allowed the highest results, with no significant difference with the yield obtained after a 160 kg N ha⁻¹ input.

Alves *et al.* (2015) conducted a field experiment to evaluate genotypes of wheat depending on doses of N in order to determine the best value of N and the components of productivity of wheat. The doses of nitrogen were: zero; 20; 40; 80 and 120 kg of N·ha⁻¹, applied at the beginning of tillering. They found that application of N increased the number of spike and grain yield. There were positive correlations between the doses of N with the number of spike and grain yield and between numbers of spike with the grain yield.

Ferrari *et al.* (2016) conducted an experiment to investigate the effect of split application of nitrogen fertilizer on the yield performance of wheat and showed that split applications of

nitrogen fertilization in tillering, booting and flowering stages increases the protein percentage (2.34%) and does not reduce grain yield due to full implementation of fertilizing at tillering stage.

Shahzad and Akmal (2017) conducted a field experiment to identify split application of N rates and timings for wheat performance. The experiment was conducted the N-application rates (i.e. NAR 0, 100, 120, 140 and 160 kg ha⁻¹) were added with different N application timings (i.e. NAT₁100% at seed bed, NAT₂ 50% at sowing and 50% 70 days after sowing, NAT₃ 25% at sowing, 50% + 70 DAS and 25% at anthesis 110 DAS and NAT₄ 25% at sowing, 25% 70 DAS and 50% 110 DAS) and reported that wheat crop fertilized with 140 kg ha⁻¹ preferably in three splits for sustainable of wheat production.

Sohail *et al.* (2018) reported that nitrogen fertilizer application (120 kg N ha⁻¹) produced significantly higher grain yield (5060 kg ha⁻¹), when it was applied in four split doses (30, 30, 30 and 30 Kg ha⁻¹) at sowing, tiller formation, stem elongation and grain filling stages, respectively (T₄). They also observed that N fertilizer application in four split doses at sowing, tiller formation, stem elongation and grain filling stages not only enhanced grain yield but also improved grain quality.

CHAPTER 3

MATERIALS AND METHODS

Materials required and methods followed in the experiments during the study period are presented in this chapter. The experiments were carried out for the two consecutive Rabi seasons during the period from November 2014 to April 2015 and November 2015 to April 2016.

3.1. Description of the experimental site

3.1.1. Location

All the experiment was conducted in the research farm and laboratory of Crop Physiology and Ecology Department, Hajee Mohammad Danesh Science and Technology University, Dinajpur-5200. Geographically the experimental field was located at 25°38' N latitude and 88°41' E longitude, with a height of 37.85 m above the sea level belonging to Agro-ecological Zone-1 (AEZ-1) named old Himalayan piedmont plain (UNDP and FAO 1988).

3.1.2. Soil and Climate

The experimental field was a medium high land with sandy loam textured soil. The pH value of the soil is 6.8. Daily weather data for the both the growing seasons were obtained at the meteorological station, Bangladesh Wheat and Maize Research Institute, Nasipur, Dinajpur, Bangladesh. A chart of the monthly air temperature (°C), rainfall (mm), relative humidity (%) and sunshine (hour's day) during the experimental period of the years (2014-15 and 2015-16) has been presented in Appendix- I. During the growing period average temperature was 21.16 °C in 2014-2015 and 21.64 °C in 2015-2016, which were suitable for wheat production. Total rainfall was 113.5 mm in 2014-2015 and 82 mm in 2015-2016 which were not sufficient for wheat production.

3.2. Experimental treatment

The treatments included in the experiment were as follows-

A. Irrigation: Levels: 4

- i) Rain-fed condition (control) - I₀
- ii) One irrigation (30 mm) was applied at crown root stage (20 days after sowing) - I₁
- iii) Two irrigations (30+30 =60 mm), first one was applied at crown root initiation stage and second was applied at maximum tillering stage - I₂

- iv) Three irrigations (30+30+30 =90 mm), first one was applied at crown root initiation stage, second was applied at maximum tillering stage and third was applied at heading stage - I₃

B. Wheat variety: 2

- i) BARI Gom 24 (V₁) ii) BARI Gom 26 (V₂)

C. Nitrogen management (urea): 4 levels

The recommended dose of nitrogen fertilizer (240 kg ha⁻¹ urea) for the crop variety under study was used for the nitrogen treatments.

Time of nitrogen application-

- i) No nitrogen (control)-N₀
- ii) All (240 kg ha⁻¹ urea) nitrogen at basal dose-N₁
- iii) One third of the N fertilizer was applied at basal dose, one third of the N fertilizer was applied at crown root initiation stage and the rest was applied at maximum tillering stage-N₂
- iv) One fourth of the N fertilizer was applied at basal dose, one fourth of the N fertilizer was applied at crown root initiation stage, one fourth was applied at maximum tillering stage and the rest was applied at heading stage -N₃

3.3. Experimental design and layout

The experiment was laid out in a split-split plot design with 3 replications. The irrigations were assigned in the main plots, wheat varieties in the sub plot and the nitrogen in the sub-sub plots. The unit plot size was 3m × 2m having a plot to plot distance 0.5m. Block to block distance was 1m. Numbers of total plots were 96.

3.4. Plant materials

Two wheat varieties (*Triticum aestivum* L.) i.e. BARI Gom 24 and BARI Gom 26 were used as planting materials. BARI Gom 24 and BARI Gom 26 were developed by Bangladesh Agricultural Research Institute (BARI) and released in 2005 and 2010 respectively. Brief descriptions of the wheat varieties are given below:

Crop characters	BARI Gham 24	BARI Gham 26
Sowing time	November	November
Plant height	95-100 cm	92-96 cm
Number of tillers	3-4	5-6
Length of spike	9-11 cm	9-11 cm
Days to heading	64-66	60-65
Seed colour	White	White
Seeds spike ⁻¹	45-50	45-50
1000- Seed weight	48-55 gm	48-52
Life cycle	102-110 days	104-110 days
Seed yield	4300-5100 kg ha ⁻¹	4000-5500 kg ha ⁻¹

3.5. Land preparation

The land of the experimental plot was opened on 10 November with a power tiller and it was made ready for sowing on 30, November by ploughing and cross ploughing with a country plough followed by laddering. All weeds and stubbles were removed from the land. The bunds around the individual plots were made firm enough to control water movement between the plots. The unit plot was spaded one day before planting and basal dose of fertilizer was incorporated thoroughly.

3.6. Fertilizer application

The land was fertilized with 180 kg TSP, 110 kg MoP, 120 kg Gypsum, 6 kg Boric Acid and 12 kg Zinc Sulphate ha⁻¹. Nitrogen was applied through urea at 240 kg ha⁻¹ as per experimental specification. The control plots received no nitrogenous fertilizer.

3.7. Collection and sowing of seeds

Seeds of designated wheat varieties were collected from Bangladesh Wheat and Maize Research Institute, Nashipur, Dinajpur. Seeds were sown continuously by hand in 20 cm apart rows @ 120 kg ha⁻¹ on 30 November, 2014 and 30 November, 2015.

3.8. Intercultural operations

3.8.1. Weeding and thinning

Weeding was done twice during the whole growing period, the one after 19 DAS and the other after 44 DAS. Thinning, weeding and gap-filling operations were done before the 1st irrigation to keep plant to plant distance approximately 4 cm.

3.8.2. Irrigation application

The plots were irrigated as per experimental specification. At each irrigation the experimental plots were irrigated with 180 litres of water which gave 30mm water depth. Proper care was taken to stop leaching of irrigated water between the adjacent plots.

3.9. Soil sample collection

Soil samples from each plot were collected for chemical analysis before sowing. The samples were then composited to make a bulk sample. Then the bulk sample was sieved to remove unwanted materials. These samples were air dried and then preserved in polythene bags for laboratory analysis. From soil sample initial soil moisture content was determined to calculate consumptive use of water and to determine water use efficiency of the crops.

3.10. Plant sample collection

From each plot five rows of crop were used for collecting data on growth and phenological parameters. Growth study was started from 20 days after sowing (DAS) and was continued up to 80 DAS at 15 days interval. Three plants per plot were carefully uprooted randomly at each time. Each plant sample was separated into leaf, stem and spike (when appear). Number of tillers plant⁻¹ was then counted. The samples were packed separately in label brown paper bags and were oven dried for 72 hrs at 70-80°C. Dry weights were then measured separately with an electrical balance. At each time, leaves from those plants were collected. The leaf area of the collected leaves was determined as function of length × maximum width × 0.75 (Mossad *et al.*, 1995).

3.11. Growth analysis technique

From each plot five rows of crop were used for collecting data on growth parameters. Growth study was started from 20 days after sowing (DAS) and continued up to 80 DAS at 15 days interval. Three plants per plot were carefully uprooted randomly at each time. Each plant sample was separated into leaf, stem and spike (when appear). Number of tillers plant⁻¹ was then counted. The samples were packed separately in label brown paper bags and were oven

dried for 72 hrs at 70-80°C. Dry weights were then measured separately with an electrical balance.

From the dry weights of different plant parts and leaf area data, the following growth attributes such as LAI, CGR, RGR, RLGR, NAR, LAR, SLA and LWR were calculated between two successive harvests by following the classical technique of growth analysis (Radford, 1967 and Hunt, 1978).

- i) Leaf Area Index (LAI) = $\frac{LA}{P}$
- ii) Crop growth Rate (CGR) = $\frac{1}{P} \times \frac{(W_2 - W_1)}{(t_2 - t_1)} \text{ gm}^{-2}\text{d}^{-1}$
- iii) Relative Growth Rate (RGR) = $\frac{(\log_e W_2 - \log_e W_1)}{(t_2 - t_1)}$
- iv) Net Assimilation Rate (NAR) = $\frac{(W_2 - W_1)(\log_e LA_2 - \log_e LA_1)}{(LA_2 - LA_1)(t_2 - t_1)}$
- v) Leaf Area Ratio (LAR) = $\frac{(\log_e W_2 - \log_e W_1)(LA_2 - LA_1)}{(W_2 - W_1)(\log_e LA_2 - \log_e LA_1)}$
- vi) Relative Leaf Growth Rate (RLGR) = $\frac{(\log_e LA_2 - \log_e LA_1)}{(t_2 - t_1)}$
- vii) Specific Leaf Area (SLA) = $(\frac{LA_1}{LW_1} + \frac{LA_2}{LW_2}) \div 2$
- viii) Leaf Weight Ratio (LWR) = $(\frac{LW_1}{W_1} + \frac{LW_2}{W_2}) \div 2$

Where P is ground area, W_2 and W_1 are the total dry weights, LA_2 and LA_1 are the leaf area, LW_2 and LW_1 are the leaf weights at latter and the former harvest, respectively.

3.12. Experimental data collection

3.12.1. Growth characters

Following parameters were calculated using the formula proposed by Radford (1967) and Hunt (1978).

1. Plant height starting from 20 to 80 DAS with an interval of 15 days.
2. Tillers plant⁻¹ starting from 20 to 80 DAS with an interval of 15 days.
3. Total dry matter plant⁻¹ starting from 20 to 80 DAS with an interval of 15 days.

4. Total dry matter m^{-2} starting from 20 to 80 DAS with an interval of 15 days.
5. Leaf area plant^{-1} starting from 20 to 80 DAS with an interval of 15 days.
6. Leaf area index (LAI) starting from 20 to 80 DAS with an interval of 15 days.
7. Crop growth rate (CGR) at 20-35, 35-50, 50-65, 65-80 DAS.
8. Relative growth rate (RGR) at 20-35, 35-50, 50-65, 65-80 DAS.
9. Net assimilation rate (NAR) at 20-35, 35-50, 50-65, 65-80 DAS.
10. Leaf area ratio (LAR) at 20-35, 35-50, 50-65, 65-80 DAS.
11. Relative leaf growth rate (RLGR) at 20-35, 35-50, 50-65, 65-80 DAS.
12. Specific leaf area (SLA) at 20-35, 35-50, 50-65, 65-80 DAS.
13. Leaf weight ratio (LWR) at 20-35, 35-50, 50-65, 65-80 DAS.

3.12.2. Phenological stages

The following stages were recorded in days when 50% plants of a variety of each replication reached to a definite stage in both the growing seasons

1. Crown root initiation stage
2. Tillering stage
3. Booting stage
4. Panicle initiation stage
5. Anthesis stage
6. Physiological maturity stage

3.12.3. Plant characteristics and dry matter at different phenological stages

The following plant characteristics were recorded at the crown root initiation, tillering, booting, heading, anthesis and physiological maturity stages.

- i) Plant height
- ii) leaf dry matter plant^{-1}
- iii) Stem dry matter plant^{-1}
- iv) Spike dry weight plant^{-1} (when present)

- v) Total dry matter plant⁻¹
- vi) Leaf area plant⁻¹

3.12.4. Water relations

3.12.4.1. Moisture retention capacity (MRC)

Moisture retention capacity of the flag leaves was measured during the anthesis stage of the crop. For this purpose, the leaves were collected in tightly fastened polythene bags. Two leaves/replication/cultivar/treatment were collected at 8:30 am and their fresh weight (FW) was taken immediately. Then the leaves were arranged systematically in a tray. After arrangement of the leaves, their fresh weight (FW) was taken at 30 minutes intervals for 8 times and there after 3 times at 90 minutes intervals. Finally, the leaves were dried in an oven at 85°C for 24 hours and their dry weight (DW) was taken by an electronic balance. The moisture retention capacity of leaves was calculated from the following formula.

$$\text{Moisture retention capacity (\%)} = \frac{\text{FW} - \text{DW}}{\text{FW}} \times 100$$

Here,

FW=Fresh weight of leaf

DW= Dry weight of leaf

3.12.4.2. Relative leaf water content (RLWC)

Relative leaf water content (RLWC) was determined from the fully expanded flag leaves. The leaves were collected at 8:00 am, 12:00 noon and 4:30 pm. Three leaves were taken from each replication of each cultivar. Their fresh weight (FW) was taken immediately and was sinked into water in petri dish and kept for 3 hours. After 3 hours, they were taken off from water and after drying with blotting paper. When the cells of the leaves were fully turgid, their turgid weight (TW) determined. Then the leaves were dried in an oven and their dry weight (DW) was taken. The relative leaf water content was calculated following formula (Barrs and Weatherly, 1962).

$$\text{Relative leaf water content (RLWC \%)} = \frac{\text{Fresh weight} - \text{Dry weight}}{\text{Turgid weight} - \text{Dry weight}} \times 100$$

3.12.5. Biochemical characters

3.12.5.1. Estimation of chlorophyll

Chlorophyll content of the flag leaves during the anthesis stage was estimated. One mg of leaf sample was taken from different portions of the flag leaf. Sample was taken in 100 ml of 80% aqueous acetone in brown colored bottle and was kept in dark for 48h. The optical density (OD) of this solution was determined against 80% acetone as blank using a spectrophotometer (Model: SPECTRO UV-VIS RS, Labomed Inc, USA) at 645 and 663 nm. The chlorophyll a, b and total chlorophyll a+b were determined according to the formulae used by Witham *et al.* (1986) as follows:

$$\text{mg chlorophyll a /g leaf tissue} = [12.7 (D 663) - 2.69 (D 645)] \times [v/(100 \times W)]$$

$$\text{mg chlorophyll b /g leaf tissue} = [22.9 (D 645) - 4.68 (D 663)] \times [v/(100 \times W)]$$

$$\text{mg total chlorophyll a+b /g leaf tissue} = [20.2 (D 645) - 8.02 (D 663)] \times [v/(100 \times W)]$$

Where, W = Fresh weight of leaf sample (1 mg)

V = Volume of the solution (10 ml)

D= Optical density

663 and 645 are wave lengths in nm.

3.12.5.2. Estimation of proline

Proline content of the flag leaves during the anthesis stage in two wheat varieties was estimated. Flag leaves from each replication of each variety was collected and immediately kept in the ice-bag and was brought to the laboratory of Crop Physiology and Ecology Department, Hajee Mohammad Danesh Science and Technology University for proline estimation. One gram fresh weight of the flag leaf was taken for proline estimation. Subsequently proline was estimated as Troll and Lindsley (1955) as follows.

At first, ninhydrin reagent was prepared in such a way so that it was utilized for proline estimation within two hours of preparation. For preparing ninhydrin reagent, addition of 30 ml glacial acetic acid and 30 ml 6 M orthophosphoric acid were mixed with 1.25 g of ninhydrin. It was subsequently heated and stirred gently to dissolve but the temperature was not allowed to exceeding 70°C. Proline standards were prepared for 0, 2, 4, 6, 8, 10, 12, 14, 16, 18 and 20 ppm with distilled water.

The fresh samples were crushed in mortar and pestle and homogenized the material in 10 ml 3% sulphosalicylic acid until no large segments of plant material remained. Homogenate was filtered through Whatman No. 2 filter paper and washed with 3% sulphosalicylic acid and the volume was set to 25 ml. Two ml of the filtrate and each standard proline solutions were then reacted with 2 ml of ninhydrin reagent and 2 ml of glacial acetic acid in a pyrex test tube and boil for one hour at 100°C in water bath covering the tube with aluminium foil to prevent excess evaporation. Subsequently, it was cool in ice bath and 4 ml of toluene was added to each tube using a dispenser. Each tube was then shaken vigorously for 15 to 20 seconds in an electrical shaker and was allowed the layer to separate for 30 minutes. The absorbance of layer was measured through spectrophotometer at 520 nm with pure toluene as a blank. Proline content was expressed on a fresh weight basis from the standard curve, using standard L-proline according to the method developed by Troll and Lindsley (1955).

3.12.6. Grain growth parameters

Grain growth study was started from the start of anthesis. After anthesis, 10 spikes from each plot were tagged with identifying marks to collect them on 7, 14, 21, 28 and 35 days after anthesis (DAA). Two spikes from each plot were collected and packed separately in labeled paper bags and were dried for 72 hours at 70-80 °C

1. Number of spikelets spike⁻¹ at 7, 14, 21, 28, 35 DAA
2. Number of grains spike⁻¹ at 14, 21, 28, 35 DAA
3. Dry weight of spike at 7, 14, 21, 28, 35 DAA
4. Dry weight grain⁻¹ at 7, 14, 21, 28, 35 DAA
5. Grain growth rate at 7-14, 14-21, 21-28, 28-35 DAA

3.12.7. Yield and yield contributing characters

The experimental crop of each plot was harvested separately at full maturity. Out of 15 rows of the crop, the central 5 rows were harvested for collecting data on yield and yield contributing characters. The harvested crop of each plot was bundled separately, tagged properly and brought to the clean threshing floor. The bundles were dried on open sunshine, threshed and then seeds were cleansed. The seed and straw weights for each plot were recorded after proper drying in the sun. Prior to harvesting, 5 plants were selected randomly from each plot and uprooted carefully for collecting data on yield contributing characters.

1. Plant height
2. Effective tillers plant⁻¹
3. Spike length
4. Extrusion length
5. Fertile spikelets spike⁻¹
6. Infertile spikelets spike⁻¹
7. 1000-grain weight
8. Grain yield
9. Straw yield
10. Biological yield
11. Harvest index

Harvest index (HI) was calculated by dividing economic yield by biological yield of the plant in each plot and by multiplying with 100 and express in percentage.

$$\text{Harvest index (\%)} = \frac{\text{Economic yield}}{\text{Biological yield}} \times 100$$

3.12.8. Association between yield and yield components

Association between yield and yield components were determined after final harvest with the help of computer package SPSS. Association was determined in respect to irrigation and nitrogen application in both the years.

3.12.9. Consumptive use of water and water use efficiency

3.12.9.1. Consumptive use of water

Soil samples were collected from each plot with an auger up to 1 meter depth of soil for determining soil moisture content before sowing and after harvest of the crop. Soil moisture was determined gravimetrically up to 1 m depth of soil profile from 5 soil layers (0-20 cm, 20-40 cm, 40-60 cm, 60-80 cm and 80-100 cm) before sowing of seeds and at the final harvest with the help of an auger. The moisture content values were used to compute consumptive water use (CWU) according to the following formula proposed by Dastane (1972).

$$\text{Consumptive use of water (mm)} = IR + ER + \sum_{i=1}^n \frac{Mb_i - Me_i}{100} \times A_i \times D_i$$

Here,

IR= Irrigation water

ER= Rainfall

Mb_i= Moisture percentage at the beginning of the season of the ith layer of the soil profile.

Me_i= Moisture percentage at the end of the season of the ith layer of the soil profile.

D_i= Depth of ith layer of the soil profile within the root zones and

n= Number of soil layers in the root zone D.

A_i=Specific density of soil.

3.12.9.2. Water use efficiency (WUE)

Water use efficiency was calculated by using the following formula

$$WUE = \frac{\text{Grain yield (kg/ha)}}{\text{Consumptive use of water (mm)}} \times 100$$

3.12.10. Estimation of nitrogen and protein in grain and straw of wheat

Straw and grain samples from each plot were taken. Approximately 10 g of samples of each plot were preserved separately in polythene bags for chemical analysis to determine N and protein content in straw and grain. Protein content in wheat straw and grain was determined by the standard micro Kjeldahl method (total nitrogen estimation method, AOAC 1980).

The samples were oven dried at 65°C overnight and grinded with a grinding machine. Wheat grain and straw samples of 0.1 g was digested with 3 ml of concentrated H₂SO₄ in presence of one Kjel-tab and two glass beads in a 75 ml Kjeldahl flask. The sample mixture was heated at 70°C for an hour over a preheated heater. After the completion of digestion, the flask was cooled at room temperature. Then the mixture was diluted to 75 ml with distilled water by inversion. For performing distillation, 10 ml of the diluted sample mixture was taken in a Buchi distillation unit with 10 ml of 40% NaOH. The distillate was collected in 10 ml 2% boric acid containing two drops of mixed indicator. The collected distillate in boric acid was titrated with 0.01 N HCl. A blank was run simultaneously to avoid the nitrogen either already

present in chemicals or atmospheric nitrogen absorbed during digestion. Then nitrogen percentage was calculated by the following formula with the help of titration value.

$$\% \text{ N} = \frac{0.014 \times \text{Normality of HCl (0.01 N)}}{10} \times \frac{v}{g} = 0.105 \times \frac{v}{g}$$

Here, v = Final volume of HCl, g = weight of sample in g.

Protein content of the straw and grain was determined by multiplying the nitrogen content of straw and grain by 6.25 and 5.83, respectively. The result was expressed in percentage.

3.12.11. N-uptake by grain and straw

N-uptake by grain and straw were calculated by the following formulae

$$\text{i. N-uptake by grain (kg ha}^{-1}\text{)} = \frac{\text{Total N (\% in grain)} \times \text{grain yield (kg ha}^{-1}\text{)}}{100}$$

$$\text{ii. N-uptake by straw (kg ha}^{-1}\text{)} = \frac{\text{Total N (\% in straw)} \times \text{straw yield (Kg ha}^{-1}\text{)}}{100}$$

3.12.12. N use efficiency

The N use efficiency of mineral N fertilization was calculated according to Craswell and Godwin, 1984, by equation

$$\text{NUE} = \frac{(\text{Grain yield}_F - \text{Grain yield}_C)}{\text{Fertilizer N applied Kg ha}^{-1}}$$

F=fertilized crop; C= unfertilized (control) crop

3.13. Cost of production

Cost of production was done by calculating the gross sell value and total expenditure (variable + permanent costs). From beginning to ending of the experiment, individual cost data on all the heads of expenditure in each treatment were recorded carefully and classified according to Mian and Bhuiya (1977) as well as posted under different heads of cost of production.

3.13.1. Input cost

Input costs were divided into two parts. These were as follows:

A. Non-material cost

The human labor was obtained from adult male laborers. Eight working hours of a laborer was considered as a man day. The mechanical labor came from the power tiller. A period of eight working hours of a power tiller was taken to be power tiller day.

B. Material cost

The seed of wheat varieties BARI Gom 24 and BARI Gom 26 as purchased from Wheat and Maize Research Institute, Nashipur, Dinajpur @ Tk.40 per kg. Chemical fertilizers e.g. Urea, TSP, MP, Gypsum, Zinc sulphate and Boric acid were bought from the authorized dealer at Dinajpur. Irrigation was done from the existing facilities of irrigation system at the research field in the Department of Crop Physiology and Ecology, Hajee Mohammad Danesh Science and Technology University, Dinajpur.

3.13.2. Overhead cost

The interest on input cost was calculated for 6 months @ Tk. 10% per year based on the interest rate of the Bangladesh Krishi Unnaun Bank. The seasonal rental cost of land was treated as land use cost. Land use cost was a fixed cost. Land use cost was TK.15000.00 per hectare for 6 months.

3.13.3 Common cost

It was arbitrarily taken to be 5% of the total running capital.

3.13.4. Gross income

Gross return from wheat cultivation (Tk. ha⁻¹) = Value of grain (Tk. ha⁻¹) + value of straw (Tk. ha⁻¹).

3.13.5. Net income

Net return was calculated by using the following formula:

$$\text{Net return (Tk. ha}^{-1}\text{)} = \text{Gross income (Tk. ha}^{-1}\text{)} - \text{total cost of production (Tk. ha}^{-1}\text{)}$$

3.13.6. Benefit cost ratio

Benefit cost ratio indicated whether the cultivation is profitable or not which was calculated as follows:

$$\text{Benefit cost ratio} = \frac{\text{Gross return (TK. ha}^{-1}\text{)}}{\text{cost of production (TK. ha}^{-1}\text{)}}$$

3.14. Meteorological data

Meteorological data was collected from the Agro-meteorological centre, Bangladesh Wheat and Maize Research Institute, Nashipur, Dinajpur, Bangladesh which is about 4km from the experimental field. The information like maximum and minimum temperature, sunshine hour and precipitation were collected from November, 2014 to April, 2015 and November, 2015 to April, 2016.

3.15. Statistical analysis and graphical presentation

All the necessary recorded parameters were analyzed statistically. A program called Microsoft Excel 2007 was used for the spreadsheet analysis and numerical calculations. The experimental design was a split-split plot with three replications for both the seasons. All the recorded data were statistically analyzed following the ANOVA technique and the significance of mean differences were adjusted by Tukey's test with the help of computer using STATA program. Simple correlation coefficients between pairs of characters were determined with the help of computer package SPSS. All the figures in the thesis were presented in the form of line graphs and bar diagrams which were composed with the help of spreadsheet package Microsoft Excel 2007.

CHAPTER 4

RESULTS AND DISCUSSION

This chapter comprised with presentation and discussion of the results obtained from the study to observe the effect of irrigation treatments, variety and split application of nitrogen on physiological attributes and yield potential of wheat plants. The effects of irrigation treatments, variety and split application of nitrogen and their interaction on physiological attributes and yield potential have been presented in Tables and Figures. The results have been presented and discussed with the help of table and graphs and possible interpretations were given under the following headings

4.1. Morphological and growth characters

4.1.1 Plant height

The data regarding the plant height of wheat as influenced by different number of irrigations at 20, 35, 50, 65 and 80 DAS are presented in Table 1a and Fig. 1a for first year (2014-15) and in Table 1b and Fig. 1b for second year (2015-16) respectively. The result suggested significant effect of irrigation levels on the plant height. Irrigation levels showed a non-significant effect on plant height at the early stages of growth (20 DAS) in both the years. Plant height for all treatments was almost similar up to the crown root initiation stage (20 DAS), as no supplemental irrigation was applied before that stage to any treatment. However, a marked decline was observed when irrigation was imposed at 20 DAS to treatment I_0 . At 35 DAS, the highest plant height was recorded from three irrigations (I_3) which was statistically similar to two (I_2) and one (I_1) irrigations in both the years. Plant height for irrigated crops was almost similar up to tillering stage, because one irrigation was applied before that stage. At 50, 65 and 80 DAS, the tallest plant was found in three (I_3) irrigations which were statistically similar to two (I_2) irrigations in both the years. The shortest plant was observed from rain-fed condition (I_0) at all growing stages in both the years. Three irrigated (I_3) crop increased plant height by applying irrigation at all critical growth stages which might be due to sufficient availability of nutrients having no moisture stress. It was observed that regardless of crops, would grew maximally under three irrigations and reduced irrigation levels up to one irrigation adversely affected the plant height. However, rain-fed condition, the wheat crop showed poor growth when compared with the performance in case of three irrigations. Shehzad *et al.* (2012) reported that the maximum plant height at I_2 (50 mm potential soil moisture deficit) may be attributed to the adequate moisture supply through all

plant growth. These results are quite in line with those of Warraich *et al.* (2007). Mandic *et al.* (2014) reported that water stress during stem elongation stage reduced the plant height because stem growth was slow. Other researchers showed that drought stress during stem elongation stage reduced the plant height (Shamsi and Kobrae, 2011 and Gevrek and Atasoy, 2012). Mollah and Paul (2011) stated that plant height increased with the increase of irrigation in barley. Similar result was reported by many researchers in wheat (Sarker and Paul 1997, Rahman *et al.*, 2001, Pandit *et al.*, 2001 and Naeem Sarwar *et al.*, 2010). Atikullah *et al.* (2014) stated that significant variation for plant height of wheat at different days after sowing due to different irrigation levels. Tallest plant was found in I₁ (irrigation at CRI stage) while shortest in I₀ (no irrigation). This result is in good agreement with the result of Islam (1997) who reported that plant height increased with increasing number of irrigations. Shirazi *et al.* (2014) observed that moisture status of soil decreased days after sowing and then gradually increased at every time of irrigation applied. It might be due to elapsed time of percolation through the soil profile.

Effects of variety on plant height of wheat at different stages of growth are shown in Table 2a for first year (2014-15) and in Table 2b for second year (2015-16) respectively. Plant height was not statistically significant for varieties in both the years.

Influence of split applications of nitrogen on plant height at different growth stages are present in Table 3a and Fig. 2a for first year (2014-15) and in Table 3b and Fig. 2b for second year (2015-16) respectively. Significant variation was observed in plant height with split applications of nitrogen at 20, 35, 50, 65 and 80 DAS under the present study in both the years. It was observed that at 20 DAS, the tallest plant was obtained in basal (N₁) application of nitrogen which was significantly differed from the remaining treatments in both the years. At 35 and 50 DAS, the highest plant height was found in basal (N₁) application of nitrogen which was statistically identical to three (N₂) and four (N₃) split applications of nitrogen in both the years. At early growth stages, amount and availability of nitrogen was high in basal dose resulting in higher plant height. But at later stages, nitrogen availability decreased rapidly because nitrogen was not applied at that period. At 65 and 80 DAS, the highest plant height was recorded in three split (N₂) applications of nitrogen which was significantly differed from the remaining treatments in both the years. The lowest plant height at 20, 35, 50, 65 and 80 DAS were observed in control (N₀) in both the years. Nitrogen is an essential element of bio-molecules such as amino acids, proteins, nucleic acids, phytohormones and a number of enzymes and co-enzymes; it's mainly involved in the initial growth processes.

Elongation of cells and plant height is one of the most important acts of auxin and there is only one known natural auxin which has proven that this compound is made from tryptophan amino acid which increased due to nitrogen (Ali *et al.*, 2011). Liaqat *et al.* (2008) stated that there was a gradual increase in plant height with each successive dose of nitrogen. By increasing nitrogen availability enhanced more leaf area resulting in higher photo assimilates and thereby resulted in more dry matter accumulation that increases maximum plant height. Chaturvedi (2006) reported that plant height increased with increasing nitrogen availability at tillering stages. Ananda (2004) reported that split application of nitrogen as three split recorded maximum plant height of wheat. Wagan *et al.* (2002) reported that nitrogen applied in three split doses significantly increased plant height.

The interaction effects of irrigation levels and split applications of nitrogen on plant height are presented in Table 4a for first year (2014-15) and in Table 4b for second year (2015-16). The interaction effect between time of irrigation and split applications of nitrogen were significant for the plant height at 20, 35, 50, 65 and 80 DAS in both the years. At 20 and 35 DAS, irrigated plant with basal application of nitrogen was produced the highest plant height. At 50 DAS, the highest plant height was recorded in $I_2 \times N_1$ which was statistically similar with $I_2 \times N_2$, $I_3 \times N_1$ and $I_3 \times N_2$ in both the years. At 65 DAS, the tallest plant was found in treatment combination of $I_3 \times N_2$ which was at par with $I_2 \times N_2$ in both the years. At 80 DAS, the highest plant height was recorded in treatment combination of $I_3 \times N_2$ which was significantly differed from the remaining treatments in both the years. The shortest plant was found in treatment combination of $I_0 \times N_0$ at 35, 50, 65 and 80 DAS but at 20 DAS, $I_1 \times N_0$ produced the shortest plant in both the years.

4.1.2. Tillers plant⁻¹

The results in regards to tillers plant⁻¹ of wheat varieties as affected by different irrigation levels are shown in Table 1a and Fig. 3a for first year (2014-15) and in Table 1b and Fig. 3b for second year (2015-16) respectively. The results indicated that the differences in tillers plant⁻¹ of wheat were significant due to different number of irrigation treatments at all the growth stages except at 20 DAS. At 35 DAS, the highest tillers plant⁻¹ was observed in three (I_3) and two (I_2) irrigations which was statistically similar with one irrigations (I_1) in both the years. At 50 DAS, the highest tillers plant⁻¹ was observed in three irrigations (I_3) which was statistically similar with two irrigations (I_2) and one (I_1) irrigation in both the years. At 65 and 80 DAS, the highest tillers plant⁻¹ was recorded in three irrigations (I_3) which was statistically similar with two irrigations (I_2) in both the years. The lowest tillers plant⁻¹ was found in rain-

fed (I_0) condition in both the growing seasons. Tillers plant^{-1} for all treatments was almost similar up to the crown root initiation stage (20 DAS), as no supplemental irrigation was applied before that stage to any treatment. However, a marked decline was observed when irrigation was imposed at 20 DAS to treatment I_0 . The increase in tillers plant^{-1} in two cultivars might be due to the sufficient availability of water at tillering stage with more uptakes of nutrients. Naeem Sarwar (2010) reported that plants irrigated with five times resulted in maximum number of tillers m^{-2} as compared to all other treatments might be due to the sufficient availability of water at tillering stage with more uptakes of nutrients. McDonald *et al.* (1984) found that maximum number of tiller was associated with higher number of irrigations. It is clear from the results that abundant moisture favour increased tillering that is why lowest number of tillers was recorded from plots irrigated at six week interval (Khan *et al.*, 2007). Mollah and Paul (2011) observed that photosynthesis and other metabolic activities were hindered by the water stress condition and as a result, plants did not have enough assimilates to afford the potential growth of all the produced tillers and thereby the number of tillers was reduced due to water stress. Atikullah *et al.* (2014) stated that number of tillers of wheat showed major variation at different DAS due to different irrigation levels. Maximum number of tillers was found in I_1 (irrigation at CRI stage) while the minimum number of tillers observed in I_0 (no irrigation). Application of two irrigations at crown root initiation stage and pre flowering stage ensured the optimum vegetative growth of the wheat with highest number of tillers hill^{-1} as referred by Meena *et al.* (1998). Gupta *et al.* (2001) reported that when water stress was imposed at the booting stage caused a greater reduced in number of tillers. Sana Ullah Baloch *et al.* (2014) reported that there was straight effect of irrigation schedules on the number of tillers plant^{-1} . Shirazi *et al.* (2014) stated that number of tillers plant^{-1} was significantly increased due to application of irrigation water.

Influence of varieties on tillers plant^{-1} at different growth stages are shown in Table 2a for first year (2014-15) and in Table 2b for second year (2015-16) respectively. The effect of variety on tillers plant^{-1} was not statistically significant at 20, 35 and 50 DAS in both the years. Significant variation for tillers plant^{-1} of wheat at 65 and 80 DAS was observed due to variety. Between the two varieties, the higher tillers plant^{-1} was recorded in BARI Gom 26 and the lower tillers plant^{-1} was recorded in BARI Gom 24 in both the years. Tillers plant^{-1} increased up to 65 DAS and thereafter declined.

The data pertaining to tillers plant^{-1} at different growth stages as significantly affected by various treatments have been presented in Table 3a and Fig. 4a for first year (2014-15) and

Table 3b and Fig. 4b for second year (2015-16) respectively. In general, the tiller production plant^{-1} increased up to 65 days after sowing and thereafter it declined due to mortality of younger tillers irrespective of the treatment. Significant variation was observed in case of tillers plant^{-1} with split application of nitrogen. At 20 and 35 DAS, the highest tillers plant^{-1} was recorded from basal (N_1) application of nitrogen which was significantly different from the remaining treatments in both the years. At early growth stages, amount and availability of nitrogen was high in basal dose resulting in higher tiller plant^{-1} . But later stages, nitrogen availability decreased rapidly because nitrogen was not applied at that period. At 50, 65 and 80 DAS, the maximum tillers plant^{-1} were observed in three splits (N_2) application of nitrogen which was statistically similar with basal (N_1) application of nitrogen in both the years. The lowest tillers plant^{-1} was recorded in control (no nitrogen application) in both the years. Chaturvedi (2006) reported that number of tillers plant^{-1} production increased with increasing nitrogen availability at all critical stages. Liaqat (2008) stated that the increase in number of tillers with the increase in nitrogen levels can be attributed to the reduction in mortality of tillers and enabling the production of more tillers from the main stem.

The interaction effect between time of irrigation and split application of nitrogen were significant for the tillers plant^{-1} at 20, 35, 50, 65 and 80 DAS in both the years and are presented in Table 4a for first year (2014-15) and in Table 4b for second year (2015-16) respectively. With some exception, at 20 and 35 DAS, irrigated plant with basal dose of nitrogen produced the highest tillers plant^{-1} . At 50, 65 and 80 DAS, the highest tillers plant^{-1} was produced in treatment combination of $I_3 \times N_2$ which was significantly different from the remaining treatments in both the years. The minimum tillers plant^{-1} was found in treatment combination of $I_0 \times N_0$ at 35, 50, 65 and 80 DAS in both the years.

Table 1a. Effect of irrigation on plant height and tillers plant⁻¹ of wheat at different day after sowing (2014-15)

Irrigation	Plant height (cm)					Tillers plant ⁻¹				
	20 DAS	35 DAS	50 DAS	65 DAS	80 DAS	20 DAS	35 DAS	50 DAS	65 DAS	80 DAS
I ₀	20.005 a	32.358 b	60.270 b	65.795 b	77.625 b	0.975 a	1.533 b	2.067 b	2.317 c	2.033 c
I ₁	20.091 a	38.661 a	63.067 ab	70.351 b	81.609 b	0.992 a	1.742 a	2.575 ab	2.917 bc	2.608 bc
I ₂	20.069 a	39.135 a	66.554 a	76.287 a	88.090 a	1.000 a	1.758 a	2.950 a	3.508 ab	3.167 ab
I ₃	20.252 a	39.426 a	66.386 a	77.766 a	91.841 a	0.938 a	1.758 a	3.008 a	3.992 a	3.667 a
CV (%)	14.220	5.635	5.402	3.492	4.087	17.632	8.520	5.077	6.693	7.838

At specific days after sowing, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

I₀- Rain-fed condition

I₁- One irrigation

I₂- Two irrigations

I₃- Three irrigations

Table 1b. Effect of irrigation on plant height and tillers plant⁻¹ of wheat at different day after sowing (2015-16)

Irrigation	Plant height (cm)					Tillers plant ⁻¹				
	20 DAS	35 DAS	50 DAS	65 DAS	80 DAS	20 DAS	35 DAS	50 DAS	65 DAS	80 DAS
I ₀	20.979 a	33.663 b	62.606 b	67.573 b	79.723 b	0.983 a	1.608 b	2.133 b	2.392 c	2.100 c
I ₁	20.847 a	38.558 a	65.105 ab	71.695 b	83.168 b	1.058 a	1.825 a	2.650 ab	2.983 bc	2.675 bc
I ₂	20.814 a	38.595 a	68.525 a	76.936 a	88.880 a	1.058 a	1.842 a	3.017 a	3.575 ab	3.233 ab
I ₃	20.995 a	38.659 a	68.288 a	77.847 a	92.425 a	1.058 a	1.842 a	3.075 a	4.058 a	3.733 a
CV (%)	14.286	5.673	5.420	3.494	4.095	14.930	9.157	4.463	6.390	7.798

At specific days after sowing, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

Table 2a. Effect of variety on plant height and tillers plant⁻¹ of wheat at different day after sowing (2014-15)

Variety	Plant height (cm)					Tillers plant ⁻¹				
	20 DAS	35 DAS	50 DAS	65 DAS	80 DAS	20 DAS	35 DAS	50 DAS	65 DAS	80 DAS
V ₁	20.177 a	37.454 a	64.083 a	72.653 a	84.854 a	0.950 a	1.621 a	2.525 a	2.758 b	2.425 b
V ₂	20.031 a	37.336 a	64.055 a	72.446 a	84.728 a	1.002 a	1.775 a	2.775 a	3.608 a	3.313 a
CV (%)	14.220	5.635	5.402	3.492	4.087	17.632	8.520	5.077	6.693	7.838

At specific days after sowing, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

V₁- BARI Gom 24

V₂- BARI Gom 26

Table 2b. Effect of variety on plant height and tillers plant⁻¹ of wheat at different day after sowing (2015-16)

Variety	Plant height (cm)					Tillers plant ⁻¹				
	20 DAS	35 DAS	50 DAS	65 DAS	80 DAS	20 DAS	35 DAS	50 DAS	65 DAS	80 DAS
V ₁	20.985 a	37.429 a	66.145 a	73.617 a	86.111 a	0.996 a	1.700 a	2.596 a	2.829 b	2.492 b
V ₂	20.833 a	37.308 a	66.117 a	73.408 a	85.986 a	1.083 a	1.858 a	2.842 a	3.675 a	3.379 a
CV (%)	14.286	5.673	5.420	3.494	4.095	14.930	9.157	4.463	6.390	7.798

At specific days after sowing, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

Table 3a. Effect of nitrogen on plant height and tillers plant⁻¹ of wheat at different day after sowing (2014-15)

Nitrogen	Plant height (cm)					Tillers plant ⁻¹				
	20 DAS	35 DAS	50 DAS	65 DAS	80 DAS	20 DAS	35 DAS	50 DAS	65 DAS	80 DAS
N ₀	18.809 d	29.696 b	54.984 b	61.450 c	74.504 c	0.258 d	0.417 d	1.442 c	1.667 c	1.408 c
N ₁	21.343 a	40.843 a	68.053 a	75.180 b	85.806 b	1.725 a	2.758 a	3.050 ab	3.617 ab	3.300 ab
N ₂	20.384 b	39.937 a	67.545 a	79.174 a	90.645 a	1.200 b	2.100 b	3.342 a	4.042 a	3.683 a
N ₃	19.881 c	39.103 a	65.694 a	74.394 b	88.210 ab	0.721 c	1.517 c	2.767 b	3.408 b	3.083 b
CV (%)	14.220	5.635	5.402	3.492	4.087	17.632	8.520	5.077	6.693	7.838

At specific days after sowing, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

N₀- Control (no nitrogen fertilizer)

N₁- All nitrogen at basal dose

N₂- Three split applications of nitrogen

N₃- Four split applications of nitrogen

Table 3b. Effect of nitrogen on plant height and tillers plant⁻¹ of wheat at different day after sowing (2015-16)

Nitrogen	Plant height (cm)					Tillers plant ⁻¹				
	20 DAS	35 DAS	50 DAS	65 DAS	80 DAS	20 DAS	35 DAS	50 DAS	65 DAS	80 DAS
N ₀	19.563 d	29.694 b	56.753 b	62.277 c	75.613 c	0.258 d	0.483 d	1.517 c	1.742 c	1.475 c
N ₁	22.198 a	40.808 a	70.244 a	76.181 b	87.080 b	1.808 a	2.842 a	3.117 ab	3.683 ab	3.367 ab
N ₂	21.198 b	39.901 a	69.719 a	80.219 a	91.985 a	1.275 b	2.175 b	3.408 a	4.108 a	3.75 a
N ₃	20.676 c	39.071 a	67.808 a	75.374 b	89.518 ab	0.817 c	1.617 c	2.833 b	3.475 b	3.15 b
CV (%)	14.286	5.673	5.420	3.494	4.095	14.930	9.157	4.463	6.390	7.798

At specific days after sowing, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

Table 4a. Interaction effect of irrigation and nitrogen on plant height and tillers plant⁻¹ of wheat at different day after sowing (2014-15)

Interaction (Irrigation × Nitrogen)	Plant height (cm)					Tillers plant ⁻¹				
	20 DAS	35 DAS	50 DAS	65 DAS	80 DAS	20 DAS	35 DAS	50 DAS	65 DAS	80 DAS
I ₀ N ₀	18.820 f	27.251 k	51.456 h	57.042 k	68.806 m	0.267 d	0.267 d	1.100 f	1.333 h	1.133 i
I ₀ N ₁	21.127 a-c	34.829 g	64.362 d	68.733 g	78.671 j	1.700 a	2.533 a	2.367 de	2.600 d-h	2.367 d-i
I ₀ N ₂	20.280 de	33.906 h	63.518 d	70.179 f	82.325 h	1.167 b	1.933 b	2.633 d	2.900 c-g	2.533 d-h
I ₀ N ₃	19.793 e	33.446 h	61.744 e	67.227 h	80.698 i	0.767 c	1.400 c	2.167 e	2.433 e-h	2.100 e-i
I ₁ N ₀	18.738 f	29.930 j	54.096 g	60.609 j	72.073 l	0.267 d	0.467 d	1.267 f	1.667 gh	1.367 hi
I ₁ N ₁	21.313 ab	42.447 bc	67.029 c	72.563 e	82.719 h	1.700 a	2.833 a	3.100 c	3.333 b-e	3.000 b-f
I ₁ N ₂	20.427 c-e	41.581 de	66.633 c	77.224 d	87.055 f	1.233 b	2.133 b	3.267 c	3.633 b-e	3.333 b-e
I ₁ N ₃	19.885 de	40.687 f	64.508 d	71.007 f	84.587 g	0.767 c	1.533 c	2.667 d	3.033 c-f	2.733 c-g
I ₂ N ₀	18.813 f	30.615 i	57.400 f	63.642 i	77.290 k	0.267 d	0.467 d	1.667 e	1.700 gh	1.467 g-i
I ₂ N ₁	21.392 a	42.959 ab	70.511 a	79.556 c	88.866 e	1.733 a	2.833 a	3.367 bc	4.033 a-c	3.633 a-d
I ₂ N ₂	20.250 de	41.888 cd	70.107 a	84.342 a	94.340 c	1.200 b	2.167 b	3.667 ab	4.500 ab	4.133 ab
I ₂ N ₃	19.822 de	41.076 ef	68.197 b	77.606 d	91.863 d	0.767 c	1.567 c	3.100 c	3.800 b-d	3.433 a-e
I ₃ N ₀	18.863 f	30.986 h	56.984 f	64.508 i	79.846 ij	0.233 d	0.467 d	1.733 e	1.967f-h	1.667 f-i
I ₃ N ₁	21.540 a	43.140 a	70.311 a	79.867 c	92.969 d	1.767 a	2.833 a	3.367 bc	4.500 ab	4.200 ab
I ₃ N ₂	20.580 b-d	42.375 bc	69.922 a	84.952 a	98.858 a	1.200 b	2.167 b	3.800 a	5.133 a	4.733 a
I ₃ N ₃	20.023 de	41.204 ef	68.326 b	81.738 b	95.693 b	0.583 cd	1.567 c	3.133 c	4.367 ab	4.067 a-c
CV (%)	14.220	5.635	5.402	3.492	4.087	17.632	8.520	5.077	6.693	7.838

At specific days after sowing, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

Table 4b: Interaction effect of irrigation and nitrogen on plant height and tillers plant⁻¹ of wheat at different DAS (2015-16)

Interaction (Irrigation × Nitrogen)	Plant height (cm)					Tillers plant ⁻¹				
	20 DAS	35 DAS	50 DAS	65 DAS	80 DAS	20 DAS	35 DAS	50 DAS	65 DAS	80 DAS
I ₀ N ₀	19.740 de	28.350 g	53.450 h	58.583 k	70.665 k	0.233 d	0.333 f	1.167 h	1.433 h	1.200 i
I ₀ N ₁	22.155 d	36.233 d	66.857 d	70.590 g	80.797 h	1.767 a	2.633 ab	2.433 de	2.667 d-h	2.433 d-i
I ₀ N ₂	21.265 c	35.273 e	65.980 d	72.075 f	84.550 f	1.167 b	2.000 cd	2.700 d	2.967 c-g	2.600 d-h
I ₀ N ₃	20.757 c	34.795 e	64.137 e	69.043 h	82.878 g	0.767 c	1.467 e	2.233 e	2.500 e-h	2.167 e-i
I ₁ N ₀	19.443 e	29.850 f	55.845 g	61.767 j	73.450 j	0.300 d	0.533 f	1.367 gh	1.733 gh	1.433 hi
I ₁ N ₁	22.117 ab	42.333 a	69.195 bc	73.950 e	84.300 f	1.767 a	2.900 a	3.167 c	3.400 b-e	3.067 b-f
I ₁ N ₂	21.193 c	41.470 b	68.787 c	78.700 d	88.718 d	1.333 b	2.200 c	3.333 c	3.700 b-e	3.400 b-e
I ₁ N ₃	20.633 cd	40.578 c	66.593 d	72.363 f	86.203 e	0.833 c	1.667 de	2.733 d	3.100 c-f	2.800 c-g
I ₂ N ₀	19.513 e	30.193 f	59.100 f	64.183 i	77.983 i	0.267 d	0.533 f	1.733 fg	1.767 gh	1.533 g-i
I ₂ N ₁	22.187 a	42.367 a	72.600 a	80.233 c	89.663 d	1.833 a	2.900 a	3.433 bc	4.100 a-c	3.700 a-d
I ₂ N ₂	21.000 c	41.310 b	72.183 a	85.040 a	95.187 b	1.300 b	2.267 bc	3.733 ab	4.567 ab	4.200 ab
I ₂ N ₃	20.557 cd	40.510 c	70.217 b	78.267 d	92.687 c	0.833 c	1.667 de	3.167 c	3.867 b-d	3.500 a-e
I ₃ N ₀	19.557 e	30.383 f	58.617 f	64.575 i	80.353 h	0.233 d	0.533 f	1.800 f	2.033 f-h	1.733 f-i
I ₃ N ₁	22.335 a	42.300 a	72.325 a	79.950 c	93.560 c	1.867 a	2.933 a	3.433 bc	4.567 ab	4.267 ab
I ₃ N ₂	21.332 bc	41.550 b	71.925 a	85.060 a	99.487 a	1.300 b	2.233 c	3.867 a	5.200 a	4.800 a
I ₃ N ₃	20.758 c	40.402 c	70.283 b	81.823 b	96.302 b	0.833 c	1.667 de	3.200 c	4.433 ab	4.133 a-c
CV (%)	14.286	5.673	5.420	3.494	4.095	14.930	9.157	4.463	6.390	7.798

At specific days after sowing, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

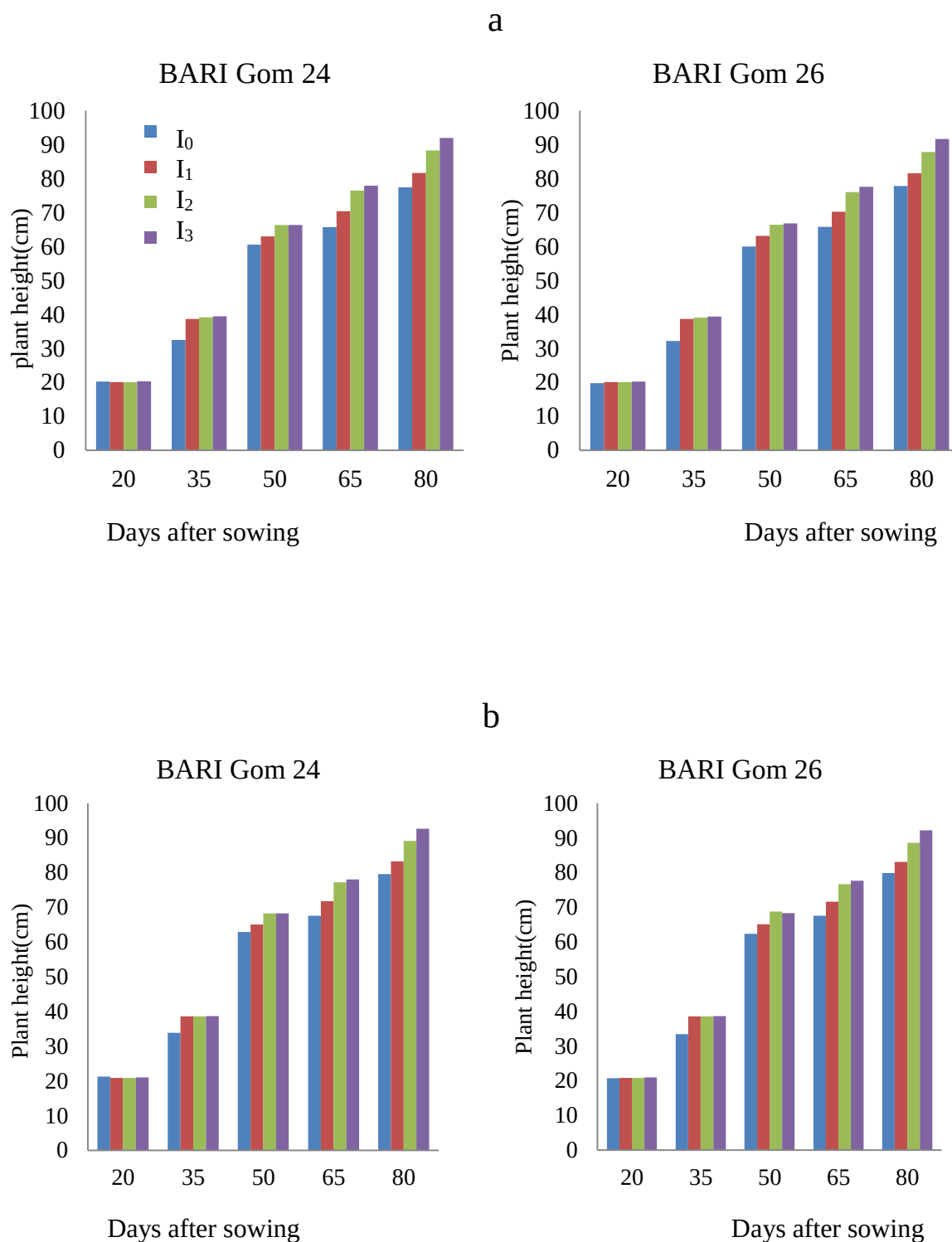


Fig. 1 Effect of irrigation on plant height at different days after sowing in 2014-15(a) and 2015-16(b)

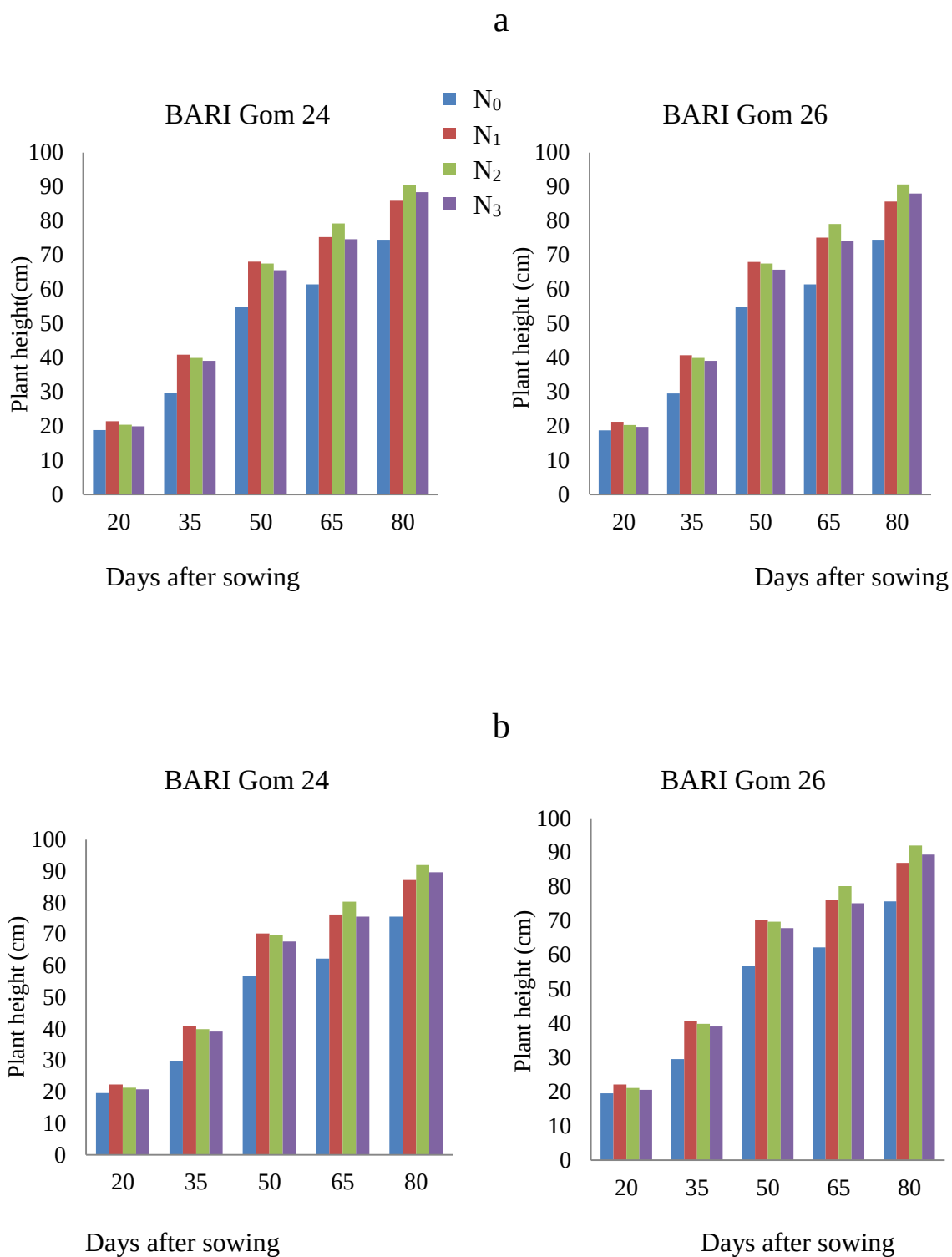


Fig. 2 Effect of nitrogen on plant height at different days after sowing in 2014-15(a) and 2015-16(b)

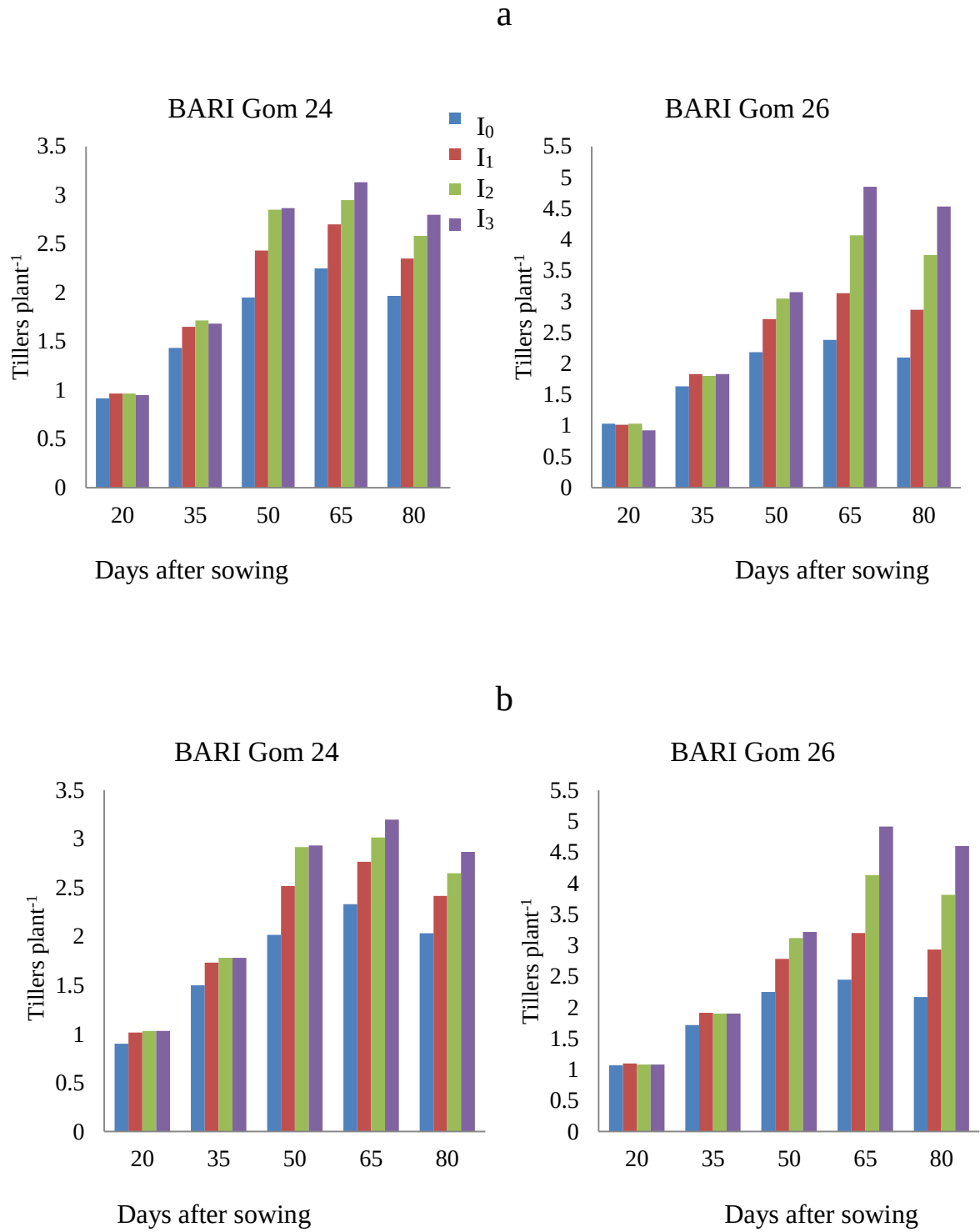


Fig. 3 Effect of irrigation on tillers plant⁻¹ at different days after sowing in 2014-15(a) and 2015-16(b)

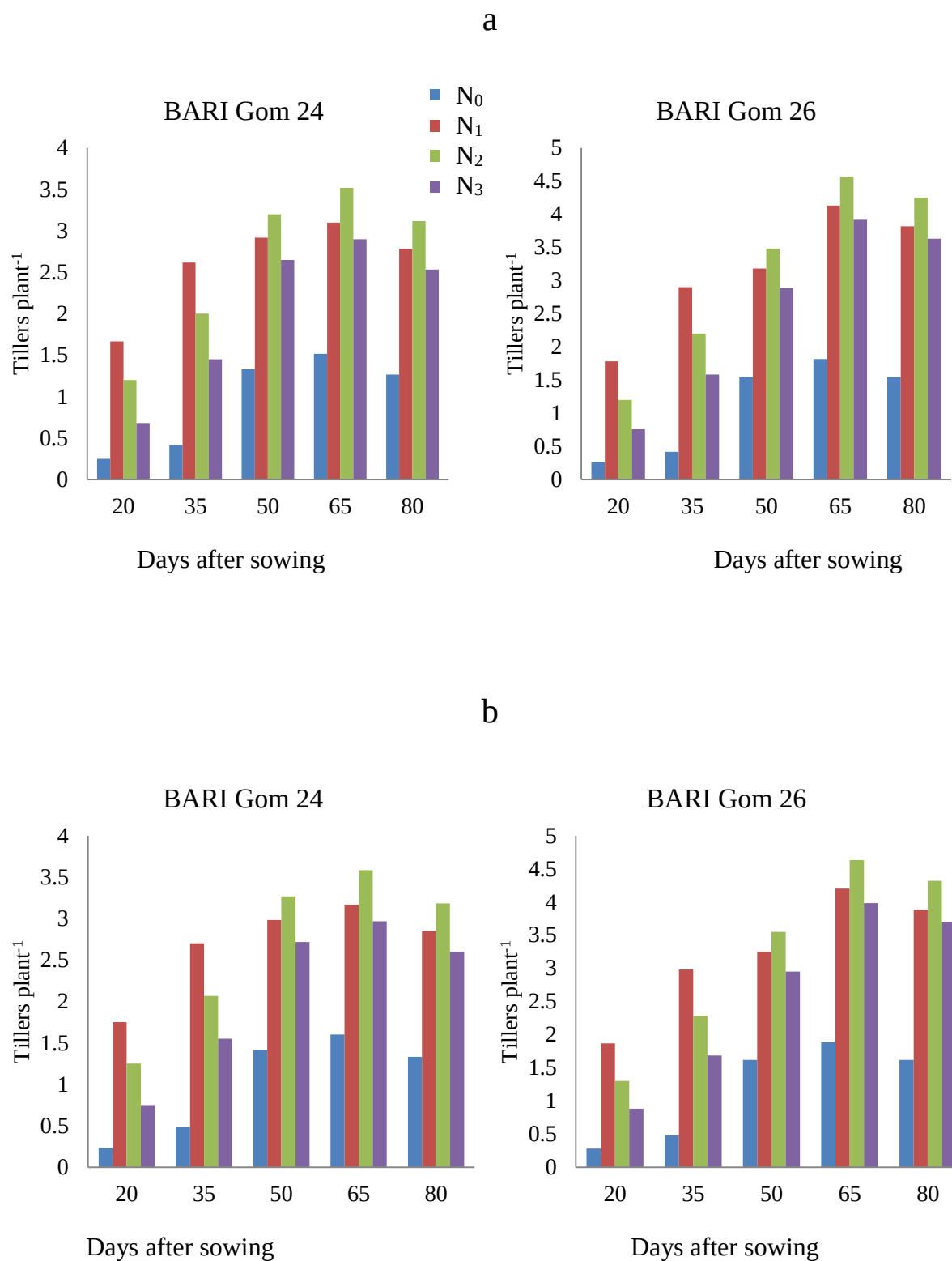


Fig. 4 Effect of nitrogen on tillers plant⁻¹ at different days after sowing in 2014-15(a) and 2015-16(b)

4.1.3. Total dry matter

The data of dry matter m^{-2} at different growth stages as affected by number of irrigation treatments are presented in Table 5a and Fig. 5a for first year (2014-15) and Table 5b and Fig. 5b for second year (2015-16) respectively. It is evident from data that dry matter production increased as the growth progressed, values being maximum at harvest, nevertheless, remained slower in first 30 days stages but they increased markedly thereafter. It is apparent from the data that the dry matter production differed significantly due to levels of irrigation at all the growth stages. Total dry matter m^{-2} was increased with the increasing number of irrigations. Total dry matter m^{-2} increased steadily until 35 DAS and then increased sharply with the advancement of growth period in both the years. At 20 DAS, the height total dry matter m^{-2} was recorded in three (I_3) irrigations which was statistically at par with one (I_1) and two (I_2) irrigations in both the years. At 35 DAS, the height total dry matter m^{-2} was found in three (I_3) irrigations which was statistically identical with two irrigations (I_2) in first years (2014-15) and statistically similar with one (I_1) and two (I_2) irrigations in second years (2015-16). At 50, 65 and 80 DAS, the highest total dry matter m^{-2} was found in three irrigations (I_3) which was statistically a par with two irrigations (I_2) in the growing seasons. The lowest total dry matter m^{-2} was observed in rain-fed (I_0) condition of all the growing periods in both the years. The increase of total dry matter m^{-2} was slow at the early vegetative phases but increased rapidly with the advancement of plant age in both the cultivars in both the years. TDM production was significantly greater in the irrigated crops than the control (I_0). The cause of rapid increased in TDM at the later stages of growth was possibly due to the development of considerable number of late tillers (Talukder, 1987). Pal and Upasani (2007) observed that four irrigations produced highest TDM than other irrigation treatments. Abdorrahmani *et al.* (2005) reported that two irrigations produced highest TDM and moisture stress reduced TDM production. Ashok and Sharma (2004) observed that the irrigation treatments increased TDM. Similar result was reported in wheat by many workers (Nahar and Paul 1998, Rahman *et al.*, 2001, Shen *et al.*, 2001, Haider 2002 and Rahman 2004). Mollah and Paul (2011) stated that the highest plant weight was in the I_2 (40 mm water as three times) treatment and the lowest was in the control in barley. These finding is corroborated with Rahman and Paul (1998) and Rahman *et al.* (2001) in wheat. Atikullah *et al.* (2014) reported that significant difference for dry matter content of wheat was found at different DAS due to different irrigation levels.

Influence of varieties on total dry matter at different growth stages are shown in Table 6a for first year (2014-15) and in Table 6b for second year (2015-16) respectively. The effect of variety significantly influenced total dry matter m^{-2} production at 20 and 35 DAS in both the growing seasons. At 50, 65 and 80 DAS, the effect of variety on total dry matter m^{-2} was not statistically significant. Between the two varieties, BARI Gom 24 (V_1) produced higher total dry matter m^{-2} than BARI Gom 26 (V_2) of all growing periods in both the years.

There was statistically significant effect of split applications of nitrogen on total dry matter m^{-2} at 20, 35, 50, 65 and 80 DAS in both the years and are presented in Table 7a and Fig. 6a for first year (2014-15) and Table 7b and Fig. 6b for second year (2015-16) respectively. At 20 and 35 DAS, the highest total dry matter m^{-2} was recorded in basal (N_1) application of nitrogen which was statistically identical to three (N_2) and four (N_3) split applications of nitrogen in both the growing seasons. At 50, 65 and 80 DAS, the highest total dry matter m^{-2} was produced in three split (N_2) applications of nitrogen which was statistically differed from the remaining treatments in both the years. The lowest values were observed in control (N_0) of all growing periods in both the years. Liaqat *et al.* (2008) stated that there was a gradual increase in total dry matter m^{-2} with each successive dose of nitrogen. By increasing nitrogen availability enhanced more leaf area resulting in higher photo assimilates and thereby resulted in more dry matter accumulation. At later stages of growing, significantly higher TDM was produced at three split applications of nitrogen than other treatments. This result might be due to the contribution of nitrogen nutrient in dry matter production. Similar trend of the effect of N was also observed in wheat by many researchers (Srivastava and Mehrotra 1980, Saini *et al.*, 1980 and Awasthi and Bhan 1993). Chaturvedi (2006) reported that TDM production increased with increasing nitrogen availability at all critical stages.

The interaction effect between number of irrigation and split applications of nitrogen were significant for total dry matter m^{-2} at all the growing periods in both the years and are showed in Table 8a for first year (2014-15) and in Table 8b for second year (2015-16) respectively. At 20 DAS, the highest TDM was recorded in treatment combination of $I_3 \times N_1$ which was statistically identical with $I_3 \times N_2$, $I_2 \times N_1$, $I_2 \times N_2$ and $I_1 \times N_1$ in the first year (2014-15) and $I_1 \times N_1$ in the second year (2015-16). At 35 DAS, the highest TDM was observed in $I_3 \times N_1$ which was at par with $I_3 \times N_2$ in the first year (2014-15) and $I_3 \times N_2$, $I_1 \times N_1$ and $I_2 \times N_1$ in the second year (2015-16). At 50, 65, and 80 DAS, treatment combination of $I_3 \times N_2$ were given the highest total dry matter m^{-2} which was differed significantly from the remaining

treatments in both the growing seasons. The lowest values at 20, 35, 50, 65 and 80 DAS were recorded in $I_0 \times N_0$ in both the years.

4.1.4. Leaf area index (LAI)

The summary of data on leaf area index at different growth stages as affected by irrigation have been presented in Table 5a and Fig. 7a for first year (2014-15) and in Table 5b and Fig. 7b for second year (2015-16) respectively. Number of irrigation had significant effect on leaf area index (LAI) at all the growing stages except at 20 DAS in both the years. At 35 DAS, the highest leaf area index (LAI) was observed in three irrigations (I_3) which was statistically identical with two (I_2) and one (I_1) irrigations in both the years. During 50, 65 and 80 DAS, the highest leaf area index (LAI) was observed in three irrigations (I_3) which was statistically similar with two irrigations (I_2) in both the years. The lowest values at 20, 35, 50, 65 and 80 DAS were found in rain-fed (I_0) in both the years. Leaf area index for all treatments was almost similar up to 20 DAS, as no supplementary irrigation was applied before that stage to any treatment. The value of LAI in the irrigated treatments was greater than the control at almost all the stages of growth. The result was in agreement with several crop plants like wheat by Leverton 1990, Nahar and Paul 1998 and Rahman 2004, in barley by Kirby 1969, in Sorghum by Constable and Hearn 1978, in mustard by Mondal and Paul 1995 and in rape by Kundu 1992. Three irrigations gave the highest LAI. The increase of LAI occurred due to increase of leaf expansion in the irrigated plants. Increase in soil moisture resulted in increased turgor pressure in the cells and turgor forces played a part in the process of leaf expansion. With an increase in the level of irrigation, uptake of nitrogen (nutrients) was more; hence more expansion of leaves took place (Mondal *et al.*, 1986). Soil moisture increased the relative leaf water content which increased cell expansion and ultimately leaf area was increased. Akram (2011) reported that drought imposed at different crop growth stages reduced LAI significantly as compared to that of the fully irrigated plants. Mandal *et al.* (2002) reported that LAI increased significantly with increasing levels of irrigation. Nahar and Paul (1998) reported that LAI was higher in irrigated plants than the rain-fed plants at all vegetative phases in wheat. They also found that LAI reach a certain peak and then declined.

The effects of variety on leaf area index (LAI) was not statistically significant are presented in Table 6a for first year (2014-15) and in Table 6b for second year (2015-16) respectively. Between the two varieties, BARI Gom 24 produced higher leaf area index (LAI) than BARI Gom 26 in both the years.

Split applications of nitrogen had significant effect on leaf area index (LAI) at different stages of growth in both the years and are present in Table 7a and Fig. 8a for first year (2014-15) and in Table 7b and Fig. 8b for second year (2015-16) respectively. At 20 and 35 DAS, significantly the highest leaf area index (LAI) values were recorded in basal (N_1) application of nitrogen which was significantly differed from the remaining treatments in both the growing seasons. At 50 DAS, the highest leaf area index (LAI) values were observed in basal (N_1) application of nitrogen which was statistically identical with three (N_2) and four (N_3) splits application of nitrogen in both the years. At 65 and 80 DAS, the highest leaf area index (LAI) was obtained in three split (N_2) applications of nitrogen which was statistically at par with four split (N_3) applications of nitrogen in both the years. The lowest leaf area index (LAI) values at different growing stages were observed in control (N_0) in both the years. In present study, significantly highest LAI was found in three split (N_2) applications of nitrogen. Similar results were reported in wheat by many scientists (Khalifa 1973, El-Hattab *et al.*, 1980, Saini *et al.*, 1980 and Awasthi and Bhan 1993). The increase in LAI was due to favourable synthesis of growth favouring constituents in plant system due to better supply of nitrogen, which led to the enlargement in leaf area.

Different treatment combinations of irrigation and nitrogen had significant influenced on leaf area index (LAI) of wheat at different days after sowing in both the growing seasons and are present in Table 8a for first year (2014-15) and in Table 8b for second year (2015-16) respectively. At 20 and 35 DAS, irrigated plant with basal dose of nitrogen ($I_1 \times N_1$, $I_2 \times N_1$ and $I_3 \times N_1$) were produced the highest leaf area index (LAI). At 50, 65 and 80 DAS, the highest leaf area index (LAI) was observed in three irrigated plants (I_3) with three split applications of nitrogen (N_2) in both the growing seasons. The lowest leaf area index (LAI) was obtained at 20, 35, 50, 65 and 80 DAS in rain-fed (I_0) $\times$ control (N_0) in both the years.

Table 5a: Effect of irrigation on total dry matter m⁻² and leaf area index of wheat at different day after sowing (2014-15)

Irrigation	Total dry matter m ⁻² (g m ⁻²)					Leaf area index (LAI)				
	20 DAS	35 DAS	50 DAS	65 DAS	80 DAS	20 DAS	35 DAS	50 DAS	65 DAS	80 DAS
I ₀	31.817 b	124.609 c	389.198 c	808.141 c	1026.228 c	0.123 a	0.948 b	1.700 c	2.690 c	3.091c
I ₁	37.027 a	148.503 b	434.078 b	901.548 bc	1144.088 bc	0.124 a	1.016 a	1.877 b	2.925 b	3.403 bc
I ₂	38.369 a	157.045 ab	468.867 ab	980.716 ab	1260.382 ab	0.123 a	1.018 a	2.018 ab	3.162 ab	3.780 ab
I ₃	39.092 a	168.854 a	509.692 a	1050.241 a	1354.679 a	0.124 a	1.020 a	2.025 a	3.189 a	4.053 a
CV (%)	6.872	16.439	6.084	3.376	2.968	2.275	2.061	6.308	6.455	8.538

At specific days after sowing, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

Table 5b: Effect of irrigation on total dry matter m⁻² and leaf area index of wheat at different day after sowing (2015-16)

Irrigation	Total dry matter m ⁻² (g m ⁻²)					Leaf area index (LAI)				
	20 DAS	35 DAS	50 DAS	65 DAS	80 DAS	20 DAS	35 DAS	50 DAS	65 DAS	80 DAS
I ₀	33.526 b	129.447 b	405.327 c	851.579 c	1051.018 c	0.129 a	0.984 b	1.727 c	2.742 c	3.151 c
I ₁	38.874 a	154.429 a	448.872 bc	934.626 bc	1165.955 bc	0.129 a	1.056 a	1.906 b	2.980 b	3.467 bc
I ₂	38.783 a	159.168 a	486.043 ab	1009.868 ab	1275.747 ab	0.129 a	1.056 a	2.049 ab	3.221 ab	3.849 ab
I ₃	39.336 a	168.497 a	509.797 a	1070.212 a	1363.627 a	0.129 a	1.057 a	2.056 a	3.249 a	4.107 a
CV (%)	6.788	16.483	7.367	3.367	2.974	2.271	2.060	6.995	6.041	8.167

At specific days after sowing, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

Table 6a: Effect of variety on total dry matter m⁻² and leaf area index of wheat at different day after sowing (2014-15)

Variety	Total dry matter m ⁻² (g m ⁻²)					Leaf area index (LAI)				
	20 DAS	35 DAS	50 DAS	65 DAS	80 DAS	20 DAS	35 DAS	50 DAS	65 DAS	80 DAS
V ₁	39.511 a	159.141 a	459.614 a	944.401 a	1202.425 a	0.123 a	1.004 a	1.910 a	2.997 a	3.593 a
V ₂	33.642 b	140.365 b	441.303 a	925.922 a	1190.264 a	0.124 a	0.997 a	1.900 a	2.986 a	3.571 a
CV (%)	6.872	16.439	6.084	3.376	2.968	2.275	2.061	6.308	6.455	8.538

At specific days after sowing, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

Table 6b: Effect of variety on total dry matter m⁻² and leaf area index of wheat at different day after sowing (2015-16)

Variety	Total dry matter m ⁻² (g m ⁻²)					Leaf area index (LAI)				
	20 DAS	35 DAS	50 DAS	65 DAS	80 DAS	20 DAS	35 DAS	50 DAS	65 DAS	80 DAS
V ₁	40.641 a	162.500 a	471.976 a	976.118 a	1220.294 a	0.129 a	1.042 a	1.939 a	3.054 a	3.655 a
V ₂	34.619 b	143.270 b	453.044 a	957.025 a	1207.879 a	0.129 a	1.035 a	1.929 a	3.042 a	3.632 a
CV (%)	6.788	16.483	7.367	3.367	2.974	2.271	2.060	6.995	6.041	8.167

At specific days after sowing, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

Table 7a: Effect of nitrogen on total dry matter m⁻² and leaf area index of wheat at different day after sowing (2014-15)

Nitrogen	Total dry matter m ⁻² (g m ⁻²)					Leaf area index (LAI)				
	20 DAS	35 DAS	50 DAS	65 DAS	80 DAS	20 DAS	35 DAS	50 DAS	65 DAS	80 DAS
N ₀	29.532 b	114.042 b	355.799 c	689.012 c	871.402 c	0.106 d	0.736 c	1.582 b	2.139 c	2.695 c
N ₁	40.005 a	166.788 a	484.198 ab	993.526 b	1262.268 b	0.135 a	1.139 a	2.051 a	3.203 b	3.750 b
N ₂	39.154 a	162.259 a	498.713 a	1049.860 a	1353.991 a	0.128 b	1.075 b	2.020 a	3.371 a	4.063 a
N ₃	37.614 a	155.923 a	463.124 b	1008.248 ab	1297.717 ab	0.126 c	1.052 b	1.967 a	3.253 ab	3.819 ab
CV (%)	6.872	16.439	6.084	3.376	2.968	2.275	2.061	6.308	6.455	8.538

At specific days after sowing, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

Table 7b: Effect of nitrogen on total dry matter m⁻² and leaf area index of wheat at different day after sowing (2015-16)

Nitrogen	Total dry matter m ⁻² (g m ⁻²)					Leaf area index (LAI)				
	20 DAS	35 DAS	50 DAS	65 DAS	80 DAS	20 DAS	35 DAS	50 DAS	65 DAS	80 DAS
N ₀	30.396 b	116.330 b	365.276 c	711.934 c	884.710 c	0.110 d	0.764 c	1.606 b	2.179 c	2.742 c
N ₁	41.153 a	170.307 a	497.169 ab	1026.989 b	1280.897 b	0.141 a	1.182 a	2.082 a	3.264 b	3.814 b
N ₂	40.274 a	165.691 a	512.085 a	1085.199 a	1373.918 a	0.133 b	1.115 b	2.062 a	3.434 a	4.133 a
N ₃	38.696 a	159.213 a	475.509 b	1042.163 ab	1316.823 ab	0.131 c	1.092 b	1.997 a	3.314 ab	3.884 ab
CV (%)	6.788	16.483	7.367	3.367	2.974	2.271	2.060	6.995	6.041	8.167

At specific days after sowing, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

Table 8a: Interaction effect of irrigation and nitrogen on total dry matter m^{-2} and leaf area index of wheat at different day after sowing (2014-15)

Interaction (Irrigation $\times$ Nitrogen)	Total dry matter m^{-2} (g m^{-2})					Leaf area index (LAI)				
	20 DAS	35 DAS	50 DAS	65 DAS	80 DAS	20 DAS	35 DAS	50 DAS	65 DAS	80 DAS
I ₀ N ₀	27.681 e	89.670 g	306.865 l	589.843 l	752.218 n	0.105 i	0.661 g	1.362 l	1.962 m	2.464 o
I ₀ N ₁	34.005 b-e	139.848 c-e	423.054 gh	865.253 h	1084.889 j	0.134 b	1.104 b	1.869 g	2.886 j	3.245 k
I ₀ N ₂	33.426 c-e	137.268 de	428.065 gh	907.189 g	1159.472 i	0.127 e	1.024 e	1.821 h	2.994 h	3.364 i
I ₀ N ₃	32.157 de	131.651 e	398.810 i	870.279 h	1108.333 j	0.125 g	1.004 e	1.748 i	2.918 i	3.291 j
I ₁ N ₀	29.050 e	108.218 fg	342.212 k	662.192 k	833.602 m	0.106 h	0.758 f	1.556 k	2.108 l	2.653 n
I ₁ N ₁	40.941 a	167.538 ab	463.745 ef	956.332 f	1201.269 h	0.136 a	1.152 a	2.018 d	3.143 g	3.553 h
I ₁ N ₂	39.919 a-c	162.513 a-c	486.769 de	1017.618 e	1301.735 f	0.129 cd	1.090 bc	1.988 e	3.269 e	3.792 f
I ₁ N ₃	38.198 a-d	155.743 b-d	443.585 fg	970.049 f	1239.746 g	0.126 ef	1.066 d	1.945 f	3.179 f	3.613 g
I ₂ N ₀	30.253 e	120.589 ef	365.707 j	717.241 j	905.547 l	0.105 i	0.761 f	1.700 j	2.237 k	2.783 m
I ₂ N ₁	42.230 a	174.637 ab	503.598 cd	1039.554 de	1328.608 e	0.134 a	1.149 a	2.155 ab	3.380 d	3.933 e
I ₂ N ₂	41.166 a	169.664 ab	519.869 c	1101.660 c	1431.516 c	0.127 e	1.092 bc	2.135 b	3.607 ab	4.384 b
I ₂ N ₃	39.826 a-c	163.293 ab	486.291 de	1064.408 d	1375.858 d	0.125 g	1.070 cd	2.081c	3.424 c	4.021 d
I ₃ N ₀	31.145 e	137.691 de	408.412 hi	786.773 i	994.242 k	0.106 h	0.764 f	1.709 j	2.249 k	2.880 l
I ₃ N ₁	42.846 a	185.129 a	546.396 ab	1112.963 bc	1434.306 c	0.136 a	1.152 a	2.137 ab	3.404 cd	4.267 c
I ₃ N ₂	42.103 a	179.590 a	560.149 a	1172.972 a	1523.240 a	0.129 c	1.094 b	2.160 a	3.613 a	4.713 a
I ₃ N ₃	40.276 ab	173.005 ab	523.810 bc	1128.257 b	1466.929 b	0.127 e	1.070 cd	2.093 c	3.490 b	4.353 b
CV (%)	6.872	16.439	6.084	3.376	2.968	2.275	2.061	6.308	6.455	8.538

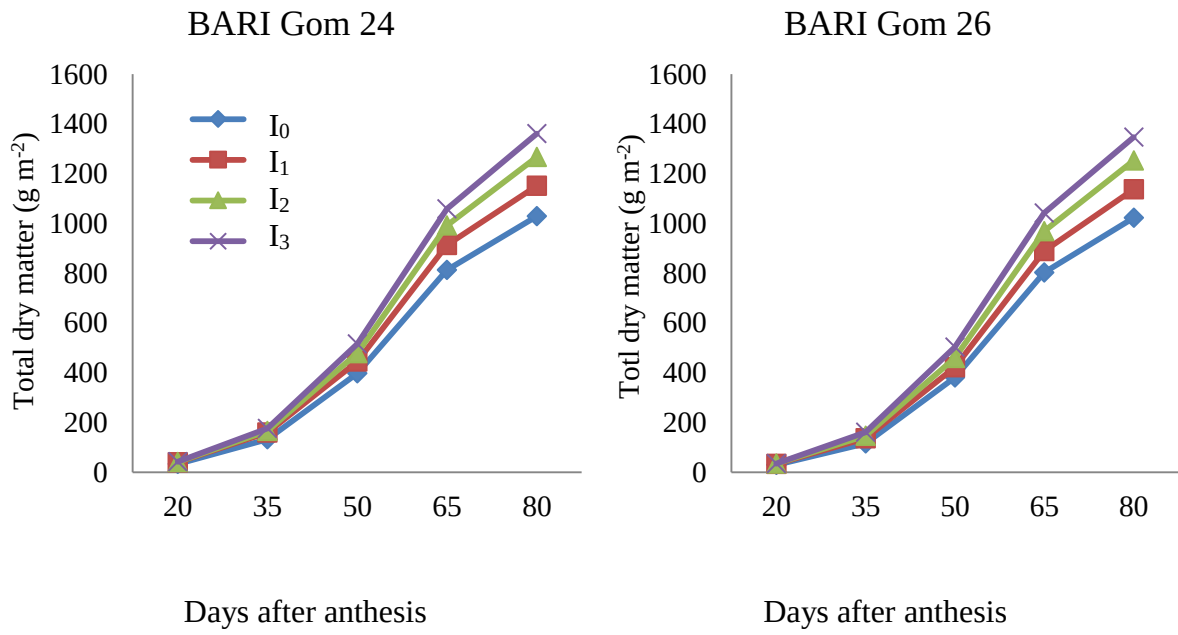
At specific days after sowing, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

Table 8b: Interaction effect of irrigation and nitrogen on total dry matter m⁻² and leaf area index of wheat at different day after sowing (2015-16)

Interaction (Irrigation × Nitrogen)	Total dry matter m ⁻² (g m ⁻²)					Leaf area index (LAI)				
	20 DAS	35 DAS	50 DAS	65 DAS	80 DAS	20 DAS	35 DAS	50 DAS	65 DAS	80 DAS
I ₀ N ₀	29.164 e	93.151 e	319.470 k	621.119 k	770.931 m	0.110 e	0.686 h	1.384 l	2.000 m	2.512 p
I ₀ N ₁	35.832 b-e	145.277 bc	440.642 g	911.919 g	1111.007 i	0.140 ab	1.146 b	1.899 g	2.941 j	3.308 l
I ₀ N ₂	35.222 c-e	142.597 bc	445.846 g	956.062 f	1187.176 h	0.133 bc	1.063 f	1.849 h	3.052 h	3.429 j
I ₀ N ₃	33.886 de	136.762 c	415.349 h	917.215 g	1134.959 i	0.131 d	1.043 f	1.776 i	2.974 i	3.355 k
I ₁ N ₀	30.499 e	112.521 de	353.873 j	686.165 j	850.099 l	0.110 e	0.787 g	1.579 k	2.148 l	2.703 o
I ₁ N ₁	42.983 a	174.228 a	479.543 ef	991.529 e	1224.020 g	0.141 a	1.196 a	2.049 d	3.202 g	3.620 i
I ₁ N ₂	41.910 a-c	169.017 ab	503.367 de	1055.074 d	1326.492 e	0.134 b	1.132 b-d	2.019 e	3.331 e	3.863 g
I ₁ N ₃	40.104 a-d	161.949 ab	458.704 fg	1005.737 e	1263.207 f	0.131 d	1.107 e	1.975 f	3.239 f	3.861 h
I ₂ N ₀	30.580 c	122.232 cd	379.120 i	738.562 i	916.919 k	0.111 e	0.789 g	1.726 j	2.279 k	2.835 n
I ₂ N ₁	42.687 ab	176.992 a	522.068 cd	1070.454 cd	1344.792 e	0.141 a	1.192 a	2.188 ab	3.443 d	4.007 f
I ₂ N ₂	41.603 a-c	171.948 ab	538.892 a-c	1134.407 b	1448.750 c	0.134 b	1.133 b-d	2.168 b	3.675 ab	4.466 b
I ₂ N ₃	40.262 a-d	165.499 ab	504.092 d	1096.047 c	1392.528 d	0.131 d	1.110 c-e	2.113 c	3.488 c	4.089 e
I ₃ N ₀	31.342 c	137.415 c	408.640 h	801.889 h	1000.890 j	0.111 e	0.792 g	1.736 j	2.291 k	2.918 m
I ₃ N ₁	43.108 a	184.730 a	546.424 ab	1134.053 b	1443.768 c	0.141 a	1.194 a	2.170 ab	3.468 cd	4.323 d
I ₃ N ₂	42.362 ab	179.202 a	560.235 a	1195.251 a	1533.252 a	0.134 b	1.134 bc	2.194 a	3.681 a	4.775 a
I ₃ N ₃	40.533 a-d	172.643 ab	523.890 b-d	1149.654 b	1476.597 b	0.132 cd	1.109 de	2.126 c	3.555 b	4.410 c
CV (%)	6.788	16.483	7.367	3.367	2.974	2.271	2.060	6.995	6.041	8.167

At specific days after sowing, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

a



b

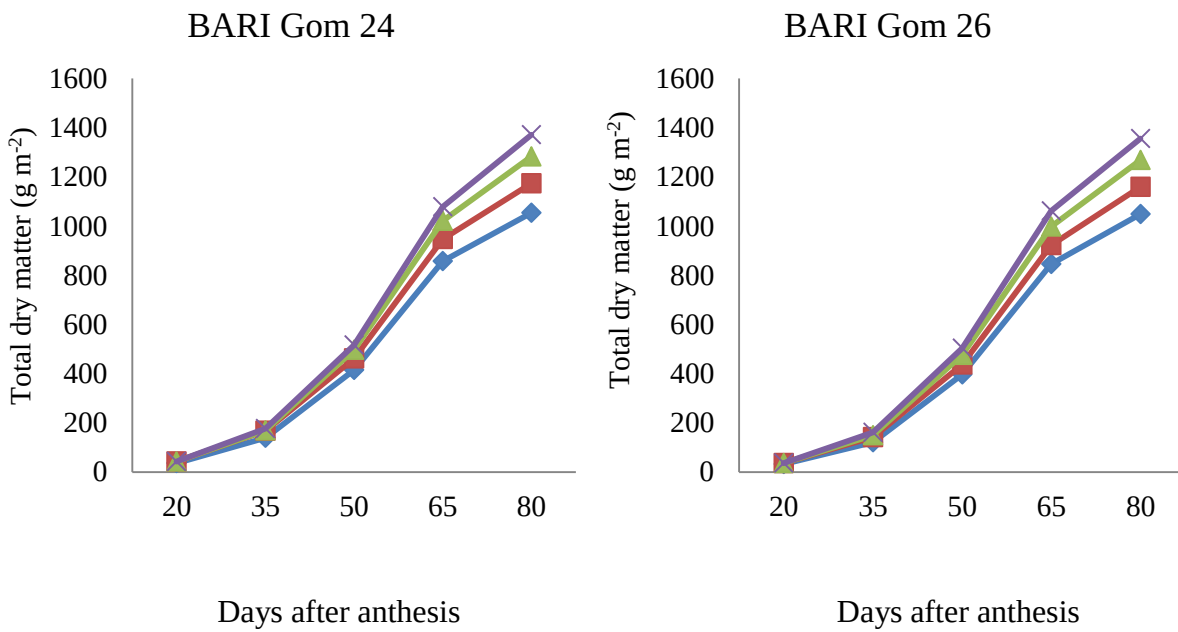
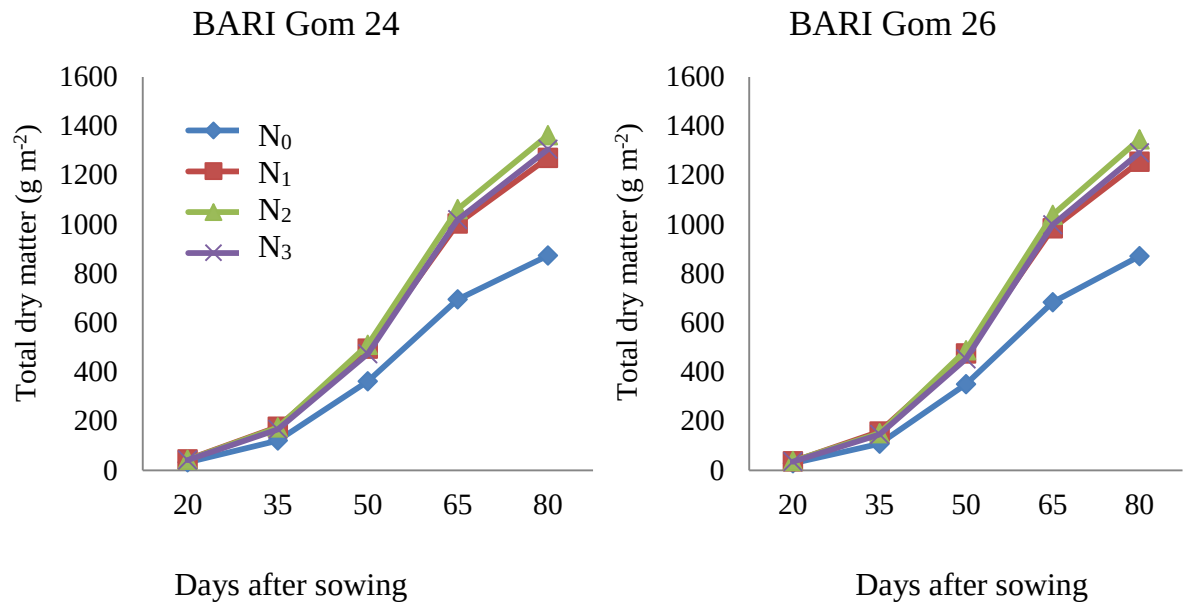


Fig. 5 Effect of irrigation on total dry matter m^{-2} at different days after sowing in 2014-15(a) and 2015-16(b)

a



b

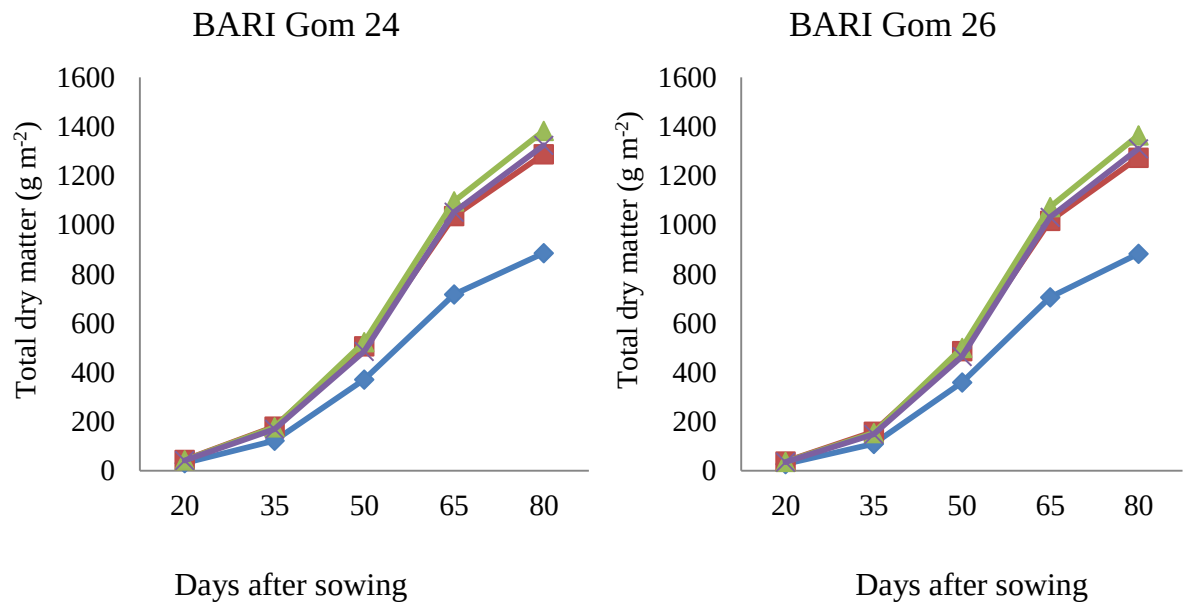
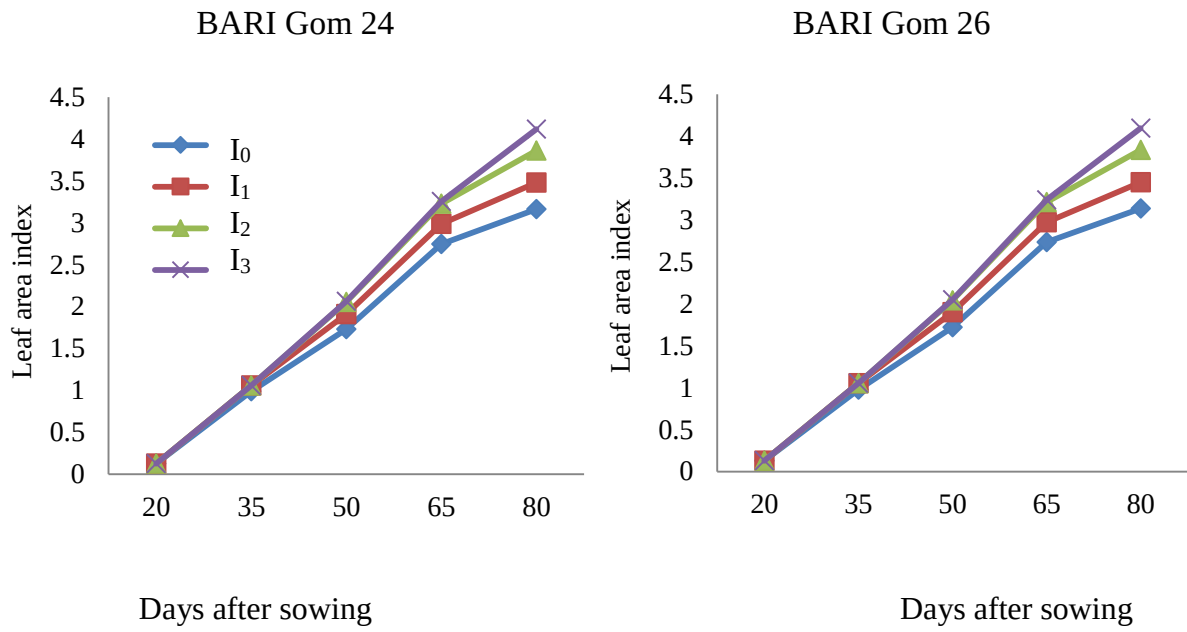


Fig. 6 Effect of nitrogen on total dry matter m^{-2} at different days after sowing in 2014-15(a) and 2015-16(b)

a



b

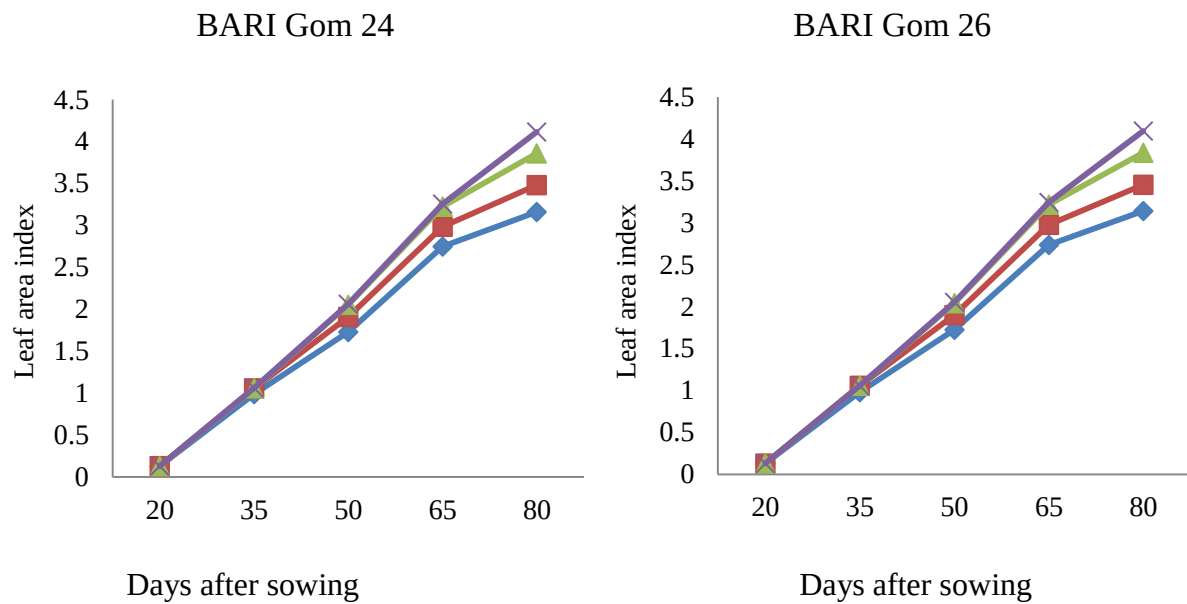
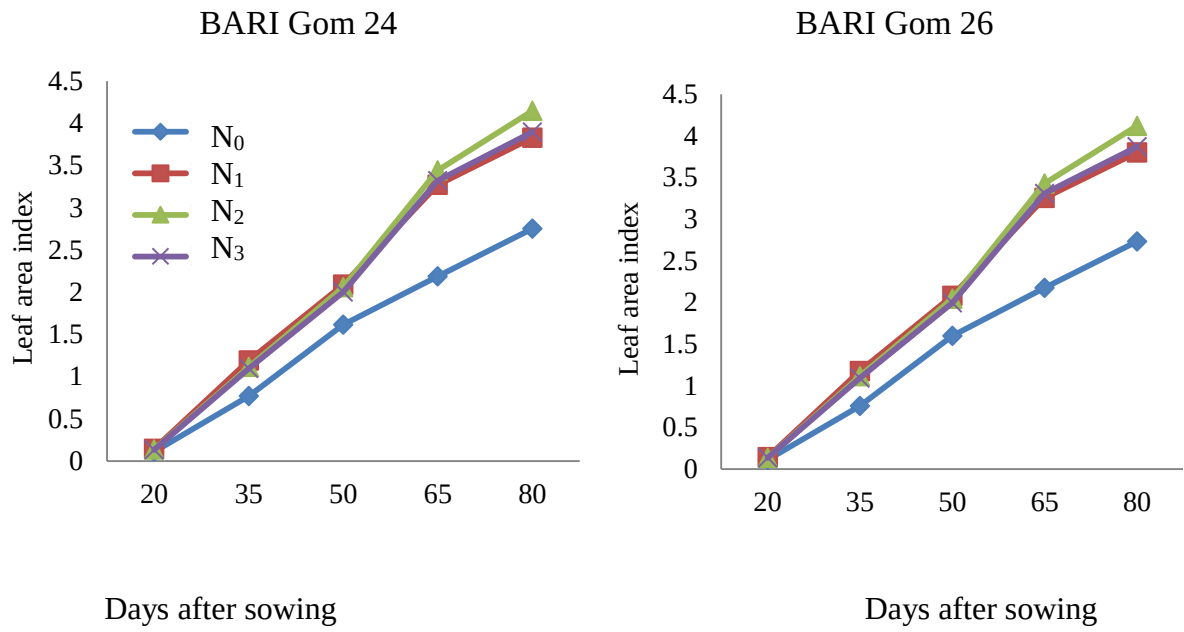


Fig. 7 Effect of irrigation on leaf area index at different days after sowing in 2014-15(a) and 2015-16(b)

a



b

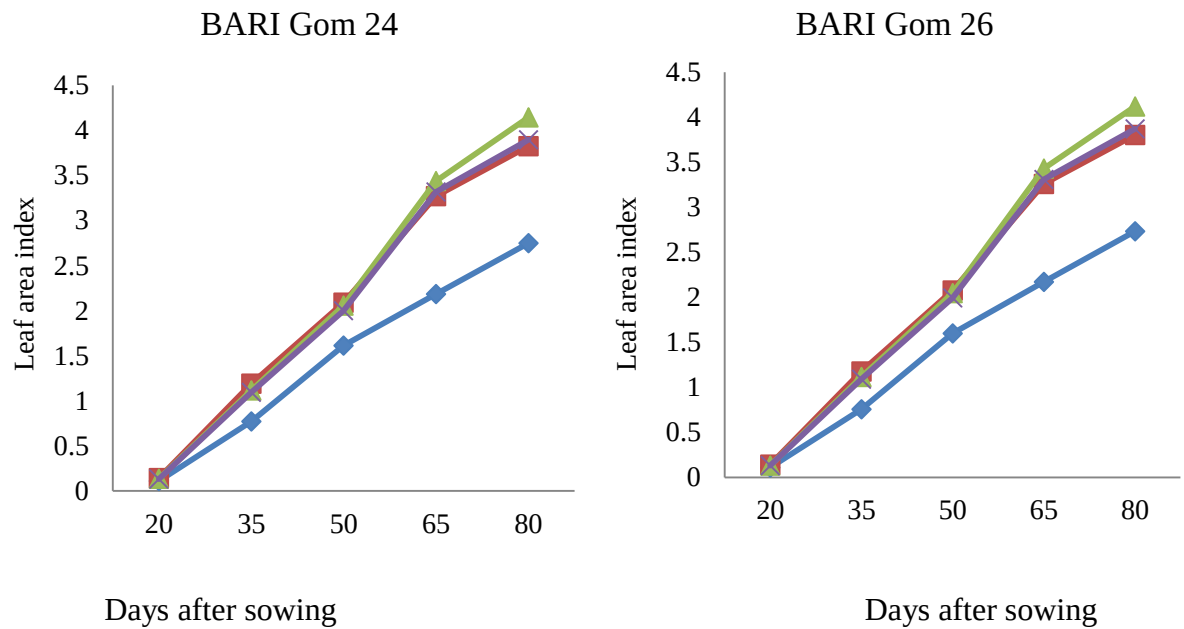


Fig. 8 Effect of nitrogen on leaf area index at different days after sowing in 2014-15(a) and 2015-16(b)

4.1.5. Crop growth rate (CGR)

Effects of irrigation on crop growth rate (CGR) are presented in Table 9a and Fig. 9a for first year (2014-15) and in Table 9b and Fig. 9b for second year (2015-16) respectively. CGR represents the net result of photosynthesis, respiration and canopy area interaction. So, it is consider more meaningful function of crop growth. In irrigation regimes, starting from a lower value, crop growth rate (CGR) reached a certain peak and thereafter declined with lower positive values. Number of irrigation showed significant effect on crop growth rate (CGR) at all the growing periods in both the years. The highest CGR was found in three irrigations (I_3) followed by two (I_2) and one (I_1) irrigation and the lowest value of CGR were obtained in rain-fed (I_0) crops at all the growing periods in both the years. CGR increased slowly at early stages of growth and reached the peak at 50-65 DAS and thereafter it declined. Similar results were reported in wheat (Nahar and Paul, 1998 and Sarker *et al.*, 1996), in sorghum (Rabiindranath and Shiv Raj, 1983), in rape (Clarke and Simpson, 1978 and Kundu, 1992) and in mustard (Mondal and Paul, 1992). Higher CGR for normal growing condition was due to higher production of dry matter owing to higher LAI (Haider, 2007). Sarker and Paul (1998) reported that CGR of wheat was higher in irrigated condition than that of rain-fed condition. Akram (2011) reported that moisture stress at different crop growth stages affected CGR differently. Fully irrigated crops indicated significantly greater CGR than other crops throughout the season. Pal *et al.* (2002) observed that application of four irrigations gave higher CGR than two or three irrigations in wheat.

Influence of varieties on crop growth rate (CGR) of wheat at different stages of growth are presented in Table 10a for first year (2014-15) and in Table 10b for second year (2015-16) respectively. The effect of variety on crop growth rate (CGR) was not statistically significant at most of the growth periods except 20-35 DAS. Between the two varieties, BARI Gom 24 produced higher CGR than BARI Gom 26 in both the years.

The effects of split applications of nitrogen on crop growth rate (CGR) at different stages of growth are shown in Table 11a and Fig. 10a for first year (2014-15) and in Table 11b and Fig. 10b for second year (2015-16) respectively. Splits application of nitrogen level had significant effect on crop growth rate (CGR) during 20-35, 35-50, 50-65 and 65-80 DAS in both the years. At 20-35 DAS, the highest CGR was found in basal (N_1) application of nitrogen which was statically identical to three (N_2) and four (N_3) split applications of nitrogen in both the growing seasons. During 35-50, 50-65 and 65-80 DAS, three splits (N_2) application of nitrogen produced highest CGR which differed significantly from the

remaining treatments in both the growing seasons. The lowest CGR during 20-35, 35-50, 50-65 and 65-80 DAS were found in control (N_0). Three split (N_2) applications of nitrogen gave the highest CGR at all growing periods except 20-35 DAS. Similar results were found in wheat by El-Shaer *et al.*, 1979 and Kumar *et al.*, 1995a. Singh and Agarwal (2001) stated that the higher LAI and LAD attained through fertilization led to high photosynthetic efficiency, which contributed to higher CGR.

Crop growth rate (CGR) varied significantly within the period of 20-35, 35-50, 50-65 and 65-80 DAS due to the interaction of number of irrigation and split applications of nitrogen in both the growing seasons and are presented in Table 12a for first year (2014-15) and in Table 12b for second year (2015-16) respectively. During 20-35 DAS, the highest crop growth rate (CGR) was observed in the treatment combination $I_3 \times N_1$ which was differed significantly from the remaining treatments in both the years. During the periods of 35-50, 50-65 and 65-80 DAS, the highest CGR was obtained in the treatment combination of $I_3 \times N_2$ which was significantly differed from the remaining treatments in both the growing seasons. The lowest values were found in $I_0 \times N_0$ in all the growing periods in both the years.

4.1.6. Relative growth rate (RGR)

Influence of irrigation treatments on relative growth rate (RGR) of wheat at successive days after sowing are presented in Table 9a and Fig. 11a for first year (2014-15) and in Table 9b and Fig. 11b for second year (2015-16) respectively. RGR is the rate of dry matter increase per unit total dry matter per unit time. Higher relative growth rate (RGR) was noticed at the early stages of growth in both the cultivars and years. Effect of irrigation on relative growth rate (RGR) varied significantly at most of the periods in both the years except 50-65 DAS. In most cases RGR were higher in the early stages of plant growth and thereafter declined steady. During 20-35 DAS, the highest RGR was observed in three irrigations (I_3) in both the years. But at 35-50 DAS, the highest RGR was found in rain-fed (I_0) condition. The highest RGR within the period of 65-80 DAS were obtained in two (I_2) and three (I_3) irrigations. This result is in agreement with that of different scientists (El-Shaer *et al.*, 1979, Saha and Paul 1995, Sarker and Paul 1998 and Rahman 2004). The reason for higher RGR values at the earlier stages of growth is possibly due to the juvenility of the plants and less effects on accumulation of dry matter. In addition to that, RGR of both cultivars decreased steadily with increasing age and plant dry weight. Decrease in RGR with increasing plant age and dry weight has been reported in wheat (Haque 1993, Rahman 1993, Tarique 2003 and Rahman 2004), in sugar beet, potato and barely (Thorne, 1960), in black gram (Pandey *et al.*, 1978), in

mustard (Mondal and Paul, 1992) and in rape (Kundu, 1992). El-Zahab *et al.* (2003) stated that RGR increased steadily during early growth stage and then decreases slowly. Thorne (1961) suggested that the decrease in RGR could be attributed to self-shading of lower leaves by upper leaves. In addition, Chanda *et al.* (1987) concluded that the declining tendency in RGR with age possibly due to decline in LAR.

The effect of varieties on relative growth rate (RGR) of wheat at different growth stages are shown in Table 10a for first year (2014-15) and in Table 10b for second year (2015-16) respectively. Relative growth rate (RGR) was influenced significantly due to variety within the period of 20-35, 35-50 and 50-65 DAS in both the years and at 65-80 DAS in the second year (2015-16). Between the two varieties, BARI Gom 26 produced higher RGR than BARI Gom 24 in both the years.

Split applications of nitrogen had significant effect on RGR during 20-35, 35-50, 50-65 and 65-80 DAS in both the years and are presented in Table 11a and Fig. 12a for first year (2014-15) and in Table 11b and Fig. 12b for second year (2015-16) respectively. During 20-35 DAS the highest RGR was observed in basal (N_1), three (N_2) and four (N_3) split applications of nitrogen in the first year (2014-15) and in the second year (2015-16), the highest RGR was found in basal (N_1) followed by three (N_2) and four (N_3) split applications of nitrogen. At 35-50 DAS, the highest RGR was found in three split (N_2) applications of nitrogen and the lowest values was obtained in control (N_0) in both the years. During 50-65 DAS the maximum RGR was observed in four (N_3) split applications of nitrogen and the lowest values was found in control (N_0). At 65-80 DAS, the highest RGR were obtained in three (N_2) and four (N_3) split applications of nitrogen in both the growing seasons. Ahmed and Farooq (2013) reported that the RGR differed significantly over the growth stages of wheat being optimum at tillering and declined with the advancement of growth, even having negative values at maturity. The given pattern of RGR can be described in term of juvenility of plants at earlier growth periods and shading effects of upper leaves on older ones at later growth stages. The results of studies conducted by Alam *et al.* (2006) had also revealed negative values at the later stages of growth. The similar pattern of RGR at different phonological stages has also been confirmed by findings of Adebo (2010). Alam *et al.* (2003) reported that nitrogen treatments exhibited the highest value of RGR. Singh and Agarwal (2001) stated that the higher LAI and LAD attained through fertilization led to high photosynthetic efficiency, which contributed to higher RGR.

Table 9 a: Effect of irrigation on crop growth rate and relative growth rate of wheat (2014-15)

Irrigation	Crop growth rate ($\text{g m}^{-2}\text{day}^{-1}$)				Relative growth rate ($\text{g g}^{-1} \text{day}^{-1}$)			
	20-35 DAS	35-50 DAS	50-65 DAS	65-80 DAS	20-35 DAS	35-50 DAS	50-65 DAS	65-80 DAS
I ₀	6.186 c	17.639 c	27.930 c	14.539 c	0.090 c	0.077 a	0.048 a	0.016 b
I ₁	7.432 b	19.038 bc	31.165 bc	16.169 bc	0.092 bc	0.072 b	0.048 a	0.016 b
I ₂	7.912 ab	20.788 b	34.123 ab	18.644 ab	0.094 b	0.073 b	0.049 a	0.017 a
I ₃	8.651 a	22.723 a	36.037 a	20.296 a	0.098 a	0.074 ab	0.048 a	0.017 a
CV (%)	2.598	3.038	4.202	6.171	9.395	9.353	7.188	7.875

At specific days after sowing, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

Table 9 b: Effect of irrigation on crop growth rate and relative growth rate of wheat (2015-16)

Irrigation	Crop growth rate ($\text{g m}^{-2}\text{day}^{-1}$)				Relative growth rate ($\text{g g}^{-1} \text{day}^{-1}$)			
	20-35 DAS	35-50 DAS	50-65 DAS	65-80 DAS	20-35 DAS	35-50 DAS	50-65 DAS	65-80 DAS
I ₀	6.395 b	18.392 b	29.750 c	13.296 c	0.089 c	0.077 a	0.049 a	0.014 c
I ₁	7.704 a	19.630 a	32.384 bc	15.422 bc	0.092 bc	0.072 b	0.049 a	0.015 b
I ₂	8.026 a	21.792 a	34.922 ab	17.725 ab	0.094 ab	0.075 ab	0.048 a	0.016 a
I ₃	8.611 a	22.753 a	37.361 a	19.561 a	0.097 a	0.074 ab	0.049 a	0.016 a
CV (%)	2.602	2.986	4.146	6.602	9.477	9.454	6.923	8.362

At specific days after sowing, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

Table 10 a: Effect of variety on crop growth rate and relative growth rate of wheat (2014-15)

Variety	Crop growth rate ($\text{g m}^{-2}\text{day}^{-1}$)				Relative growth rate ($\text{g g}^{-1} \text{day}^{-1}$)			
	20-35 DAS	35-50 DAS	50-65 DAS	65-80 DAS	20-35 DAS	35-50 DAS	50-65 DAS	65-80 DAS
V ₁	7.975 a	20.032 a	32.319 a	17.623 a	0.092 b	0.071 b	0.048 b	0.016 b
V ₂	7.115 b	20.063 a	32.308 a	17.202 a	0.095 a	0.077 a	0.049 a	0.017 a
CV (%)	2.598	3.038	4.202	6.171	9.395	9.353	7.188	7.875

At specific days after sowing, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

Table 10 b: Effect of variety on crop growth rate and relative growth rate of wheat (2015-16)

Variety	Crop growth rate ($\text{g m}^{-2}\text{day}^{-1}$)				Relative growth rate ($\text{g g}^{-1} \text{day}^{-1}$)			
	20-35 DAS	35-50 DAS	50-65 DAS	65-80 DAS	20-35 DAS	35-50 DAS	50-65 DAS	65-80 DAS
V ₁	8.124 a	20.632 a	33.609 a	16.278 a	0.092 b	0.071 b	0.048 b	0.015 a
V ₂	7.243 b	20.652 a	33.599 a	16.724 a	0.094 a	0.077 a	0.050 a	0.015 a
CV (%)	2.602	2.986	4.146	6.602	9.477	9.454	6.923	8.362

At specific days after sowing, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

Table 11 a: Effect of nitrogen on crop growth rate and relative growth rate of wheat (2014-15)

Nitrogen	Crop growth rate ($\text{g m}^{-2}\text{day}^{-1}$)				Relative growth rate ($\text{g g}^{-1} \text{day}^{-1}$)			
	20-35 DAS	35-50 DAS	50-65 DAS	65-80 DAS	20-35 DAS	35-50 DAS	50-65 DAS	65-80 DAS
N ₀	5.634 b	16.117 c	22.214c	12.159 c	0.089 b	0.076 a	0.044 d	0.016 b
N ₁	8.452 a	21.161 ab	33.955 b	17.916 b	0.095 a	0.071 c	0.048 c	0.016 b
N ₂	8.207 a	22.430 a	36.743 a	20.275 a	0.095 a	0.075 ab	0.050 b	0.017 a
N ₃	7.887 a	20.480 b	36.342 ab	19.298 ab	0.095 a	0.073 bc	0.052 a	0.017 a
CV (%)	2.598	3.038	4.202	6.171	9.395	9.353	7.188	7.875

At specific days after sowing, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

Table 11 b: Effect of nitrogen on crop growth rate and relative growth rate of wheat (2015-16)

Nitrogen	Crop growth rate ($\text{g m}^{-2}\text{day}^{-1}$)				Relative growth rate ($\text{g g}^{-1} \text{day}^{-1}$)			
	20-35 DAS	35-50 DAS	50-65 DAS	65-80 DAS	20-35 DAS	35-50 DAS	50-65 DAS	65-80 DAS
N ₀	5.729 b	16.596 c	23.111 c	11.518 c	0.089 b	0.077 a	0.044 d	0.014 b
N ₁	8.610 a	21.791 ab	35.321 b	16.927 b	0.095 a	0.072 c	0.048 c	0.015 b
N ₂	8.361 a	23.093 a	38.208 a	19.248 a	0.094 a	0.075 ab	0.050 b	0.016 a
N ₃	8.034 a	21.086 b	37.777 ab	18.311 ab	0.094 a	0.073 bc	0.052 a	0.016 a
CV (%)	2.602	2.986	4.146	6.602	9.477	9.454	6.923	8.362

At specific days after sowing, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

Table 12a: Interaction effect of irrigation and nitrogen on crop growth rate and relative growth rate of wheat (2014-15)

Interaction (Irrigation × Nitrogen)	Crop growth rate (g m ⁻² day ⁻¹)				Relative growth rate (g g ⁻¹ day ⁻¹)			
	20-35 DAS	35-50 DAS	50-65 DAS	65-80 DAS	20-35 DAS	35-50 DAS	50-65 DAS	65-80 DAS
I ₀ N ₀	4.133 h	14.480 l	18.865 l	10.825 l	0.078 g	0.082 a	0.044 f	0.016 ab
I ₀ N ₁	7.056 ef	18.880 h	29.480 h	14.642 i	0.094 c-e	0.074 b-d	0.048 de	0.015 c
I ₀ N ₂	6.923 ef	19.386 g	31.942 g	16.819 g	0.094 c-e	0.076 a-c	0.050 bc	0.016 ab
I ₀ N ₃	6.633 f	17.811 i	31.431 g	15.870 h	0.094 c-e	0.074 b-c	0.052 a	0.016 ab
I ₁ N ₀	5.278 g	15.600 k	21.332 k	11.427 l	0.088 f	0.077 ab	0.044 f	0.015 c
I ₁ N ₁	8.440 a-c	19.747 f	32.839 f	16.329 gh	0.094 c-e	0.068 d	0.048 c-e	0.015 c
I ₁ N ₂	8.173 b-d	21.617 e	35.390 de	18.941 e	0.094 de	0.073 b-d	0.049 c-e	0.016 ab
I ₁ N ₃	7.836 c-e	19.189 g	35.098 e	17.980 f	0.094 de	0.070 cd	0.052 a	0.016 ab
I ₂ N ₀	6.022 fg	16.341 j	23.436 j	12.554 k	0.092 e	0.074 b-d	0.045 f	0.016 ab
I ₂ N ₁	8.827 a-c	21.931 d	35.730 d	19.270 e	0.095 c-e	0.071 b-d	0.048 c-e	0.016 ab
I ₂ N ₂	8.566 a-c	23.347 c	38.786 b	21.990 bc	0.095 c-e	0.075 bc	0.050 bc	0.017 a
I ₂ N ₃	8.231 bc	21.533 e	38.541 b	20.763 d	0.094 c-e	0.073 b-d	0.052 a	0.017 a
I ₃ N ₀	7.103 d-f	18.048 i	25.224 i	13.831 j	0.097 a-c	0.073 b-d	0.044 f	0.016 b
I ₃ N ₁	9.486 a	24.085 b	37.771 c	21.423 cd	0.099 a	0.072 b-d	0.047 e	0.017 a
I ₃ N ₂	9.166 ab	25.371 a	40.855 a	23.351 a	0.098 ab	0.076 a-c	0.049 cd	0.017 a
I ₃ N ₃	8.849 a-c	23.387 c	40.296 a	22.578 b	0.097 a-c	0.074 b-d	0.051 ab	0.018 a
CV (%)	2.598	3.038	4.202	6.171	9.395	9.353	7.188	7.875

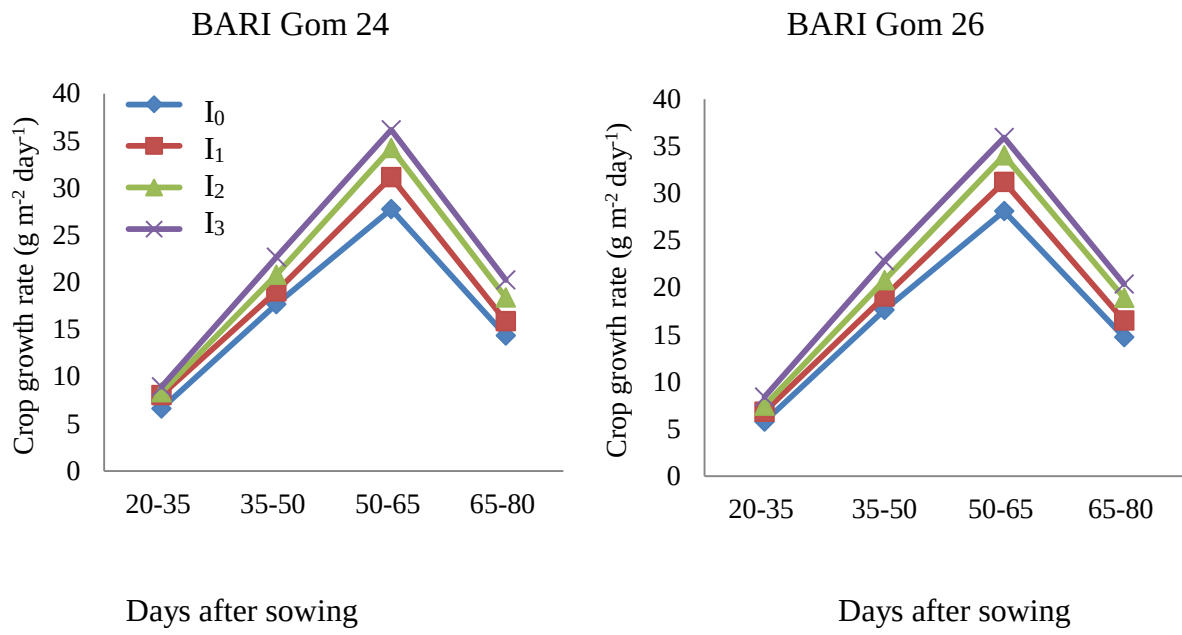
At specific days after sowing, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

Table 12 b: Interaction effect of irrigation and nitrogen on crop growth rate and relative growth rate of wheat (2015-16)

Interaction (Irrigation × Nitrogen)	Crop growth rate (g m ⁻² day ⁻¹)				Relative growth rate (g g ⁻¹ day ⁻¹)			
	20-35 DAS	35-50 DAS	50-65 DAS	65-80 DAS	20-35 DAS	35-50 DAS	50-65 DAS	65-80 DAS
I ₀ N ₀	4.266 h	15.088 m	20.110 k	9.987 l	0.077 f	0.082 a	0.044 f	0.014 d-f
I ₀ N ₁	7.296 c-e	19.691 h	31.418 g	13.273 i	0.093 b-d	0.074 bc	0.049 e	0.013 g
I ₀ N ₂	7.158 d-f	20.217 g	34.014 ef	15.408 g	0.093 b-d	0.076 ab	0.051 b-d	0.014 d-f
I ₀ N ₃	6.858 ef	18.572 i	33.458 f	14.516 h	0.093 b-d	0.074 bc	0.053 a	0.014 d-f
I ₁ N ₀	5.468 g	16.090 l	22.153 j	10.929 k	0.087 e	0.076 ab	0.044 f	0.014 d-f
I ₁ N ₁	8.750 ab	20.354 g	34.132 e	15.499 g	0.093 b-d	0.068 d	0.048 e	0.014 d-f
I ₁ N ₂	8.474 ab	22.290 f	36.780 d	18.095 e	0.093 b-d	0.073 b-d	0.049 de	0.015 b-d
I ₁ N ₃	8.123 b-d	19.784 h	36.469 d	17.165 f	0.093 b-d	0.070 cd	0.052 ab	0.015 b-d
I ₂ N ₀	6.110 fg	17.126 k	23.963 i	11.890 j	0.092 d	0.076 ab	0.044 f	0.014 d-f
I ₂ N ₁	8.954 ab	23.005 e	36.560 d	18.289 e	0.095 a-d	0.072 b-d	0.048 e	0.015 b-d
I ₂ N ₂	8.690 ab	24.463 b	39.701 c	20.956 c	0.095 a-d	0.076 ab	0.050 de	0.016 ab
I ₂ N ₃	8.349 a-c	22.573 f	39.464 c	19.765 d	0.094 b-d	0.074 bc	0.052 ab	0.016 ab
I ₃ N ₀	7.072 d-f	18.082 j	26.217 h	13.267 i	0.096 a-d	0.073 b-d	0.045 f	0.015 b-d
I ₃ N ₁	9.441 a	24.113 c	39.175 c	20.648 c	0.099 a	0.072 b-d	0.049 e	0.016 ab
I ₃ N ₂	9.123 ab	25.402 a	42.334 a	22.533 a	0.097 ab	0.076 ab	0.051 b-d	0.017 a
I ₃ N ₃	8.807 ab	23.416 d	41.718 b	21.796 b	0.097 ab	0.074 bc	0.052 ab	0.017 a
CV (%)	2.602	2.986	4.146	6.602	9.477	9.454	6.923	8.362

At specific days after sowing, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

a



b

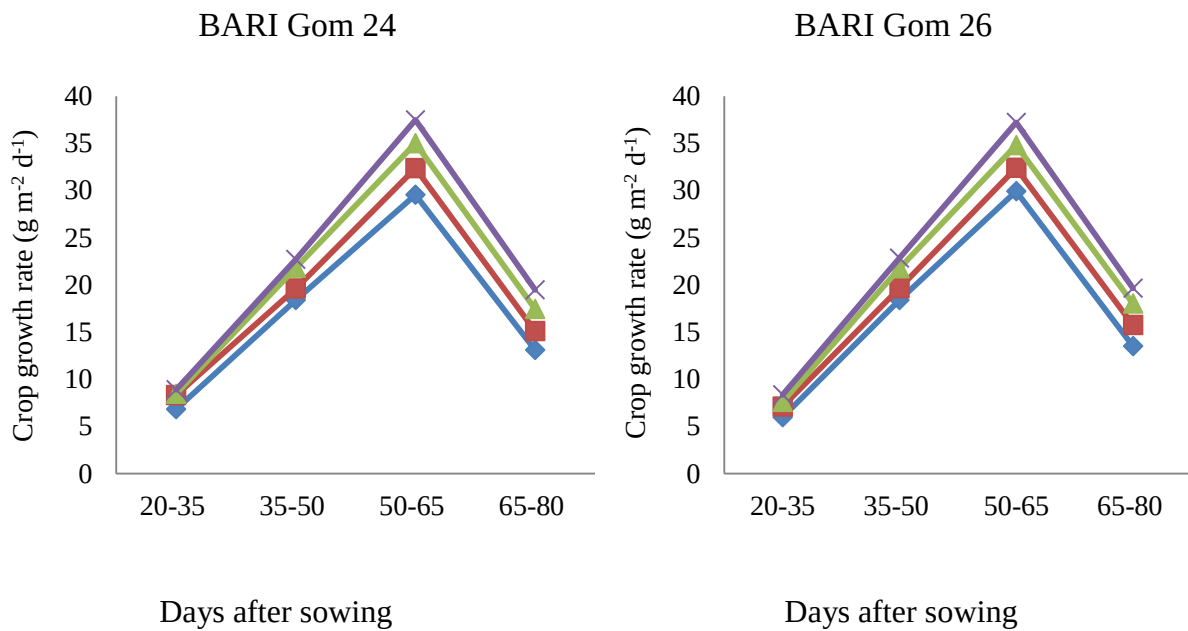
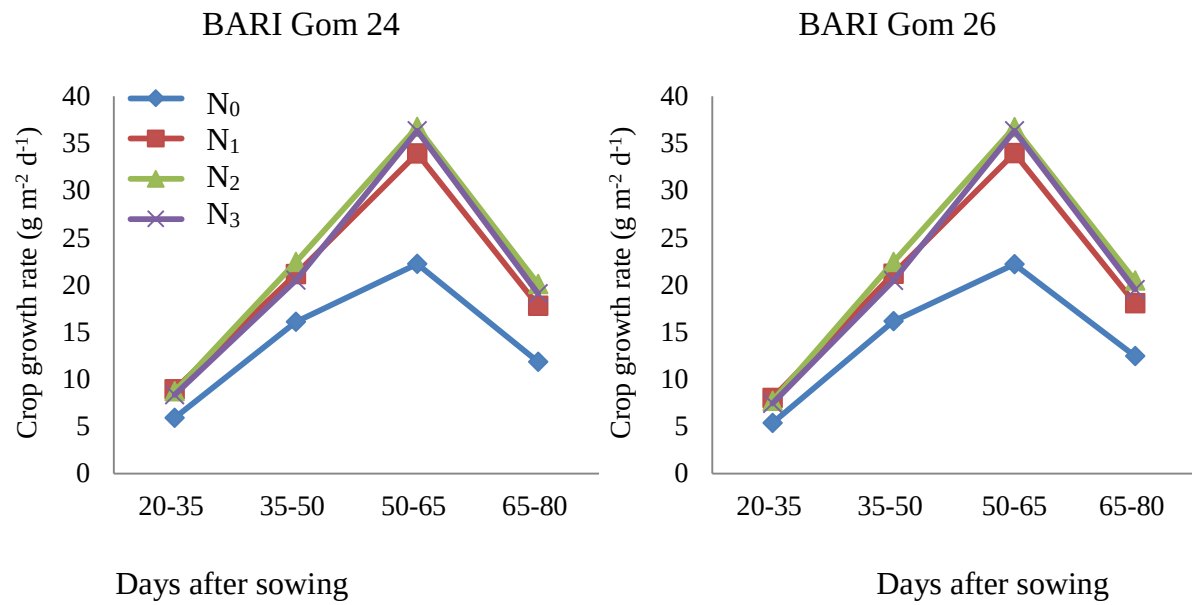


Fig. 9 Effect of irrigation on crop growth rate at different days after sowing in 2014-15(a) and 2015-16(b)

a



b

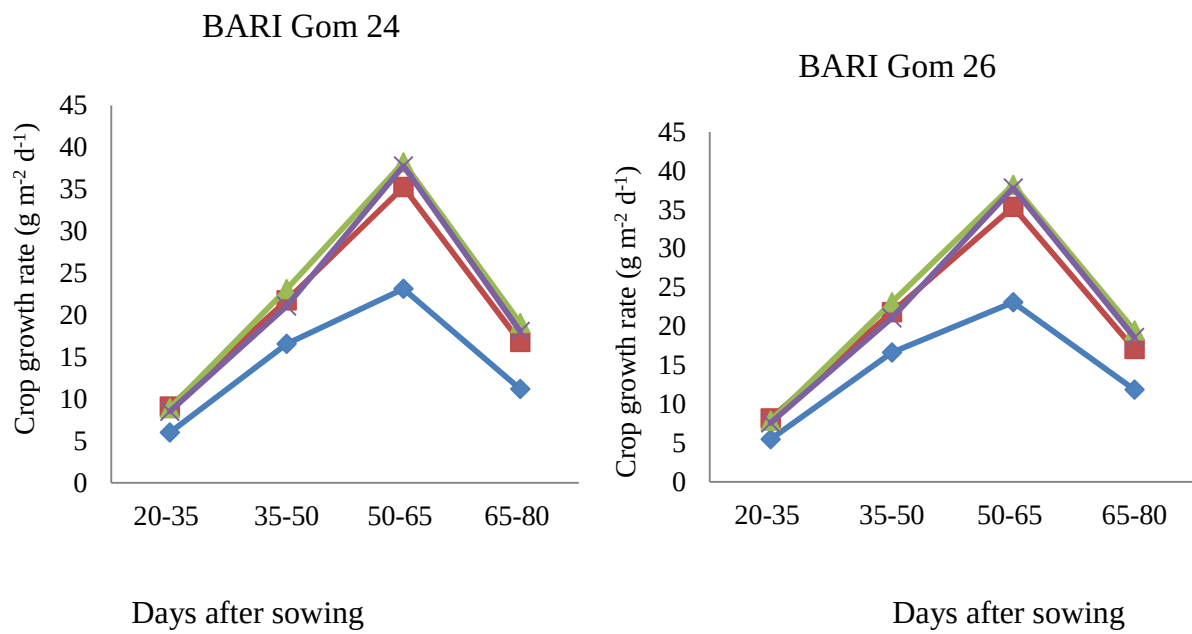


Fig. 10 Effect of nitrogen on crop growth rate at different days after sowing in 2014-15(a) and 2015-16(b)

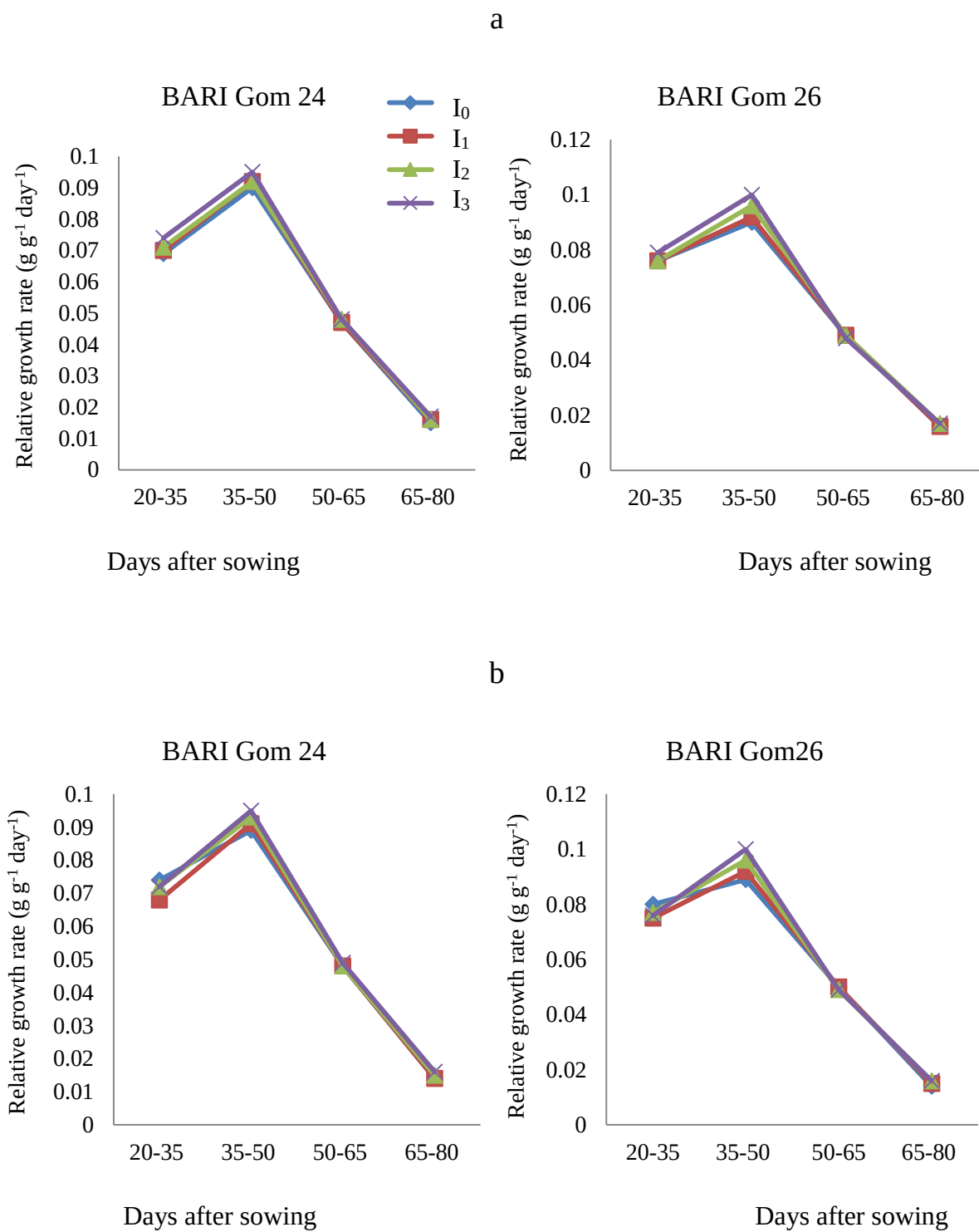


Fig. 11 Effect of irrigation on relative growth rate at different days after sowing in 2014-15(a) and 2015-16(b)

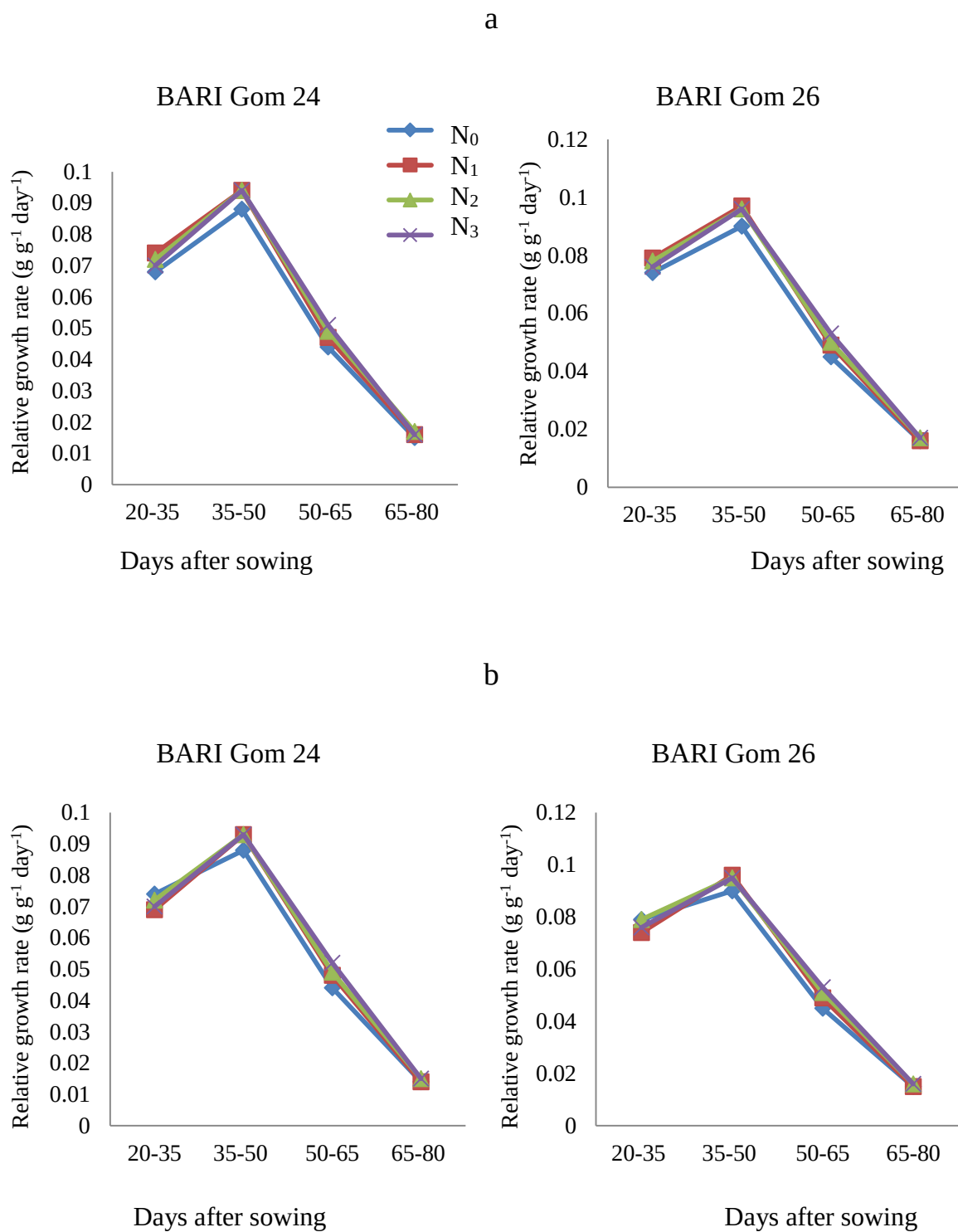


Fig. 12 Effect of nitrogen on relative growth rate at different days after sowing in 2014-15(a) and 2015-16(b)

Relative growth rate (RGR) was significantly influenced due to the interaction of number of irrigation and split applications of nitrogen during 20-35, 35-50, 50-65 and 65-80 DAS in both the years and are presented in Table 12a for first year (2014-15) and in Table 12b for second year (2015-16) respectively. During 20-35 DAS, the highest relative growth rate (RGR) was obtained by treatment combination of $I_3 \times N_1$ in both the year and the lowest value was obtained in treatment combination of $I_0 \times N_0$. But at 35-50 DAS, the highest RGR was observed in treatment combination of $I_0 \times N_0$ in both the years. During 50-65 DAS, the highest RGR was obtained by $I_0 \times N_3$, $I_1 \times N_3$ and $I_2 \times N_3$ in the first year (2014-15) and the highest RGR was found in $I_0 \times N_3$ in the second year (2015-16). At 65-80 DAS, the highest RGR was found in treatment combination of $I_3 \times N_3$ followed by $I_3 \times N_2$, $I_3 \times N_1$, $I_2 \times N_2$ and $I_2 \times I_3$ in the first year (2014-15) and the highest RGR was recorded in $I_3 \times N_2$ and $I_3 \times N_3$ in second year (2015-16).

4.1.7. Net assimilation rate (NAR)

The effect of irrigation treatments on net assimilation rate (NAR) at successive days after sowing are presented in Table 13a and Fig. 13a for 2014-15 and Table 13b and Fig. 13b for 2015-16 respectively. Irrigation treatments showed significant effect on net assimilation rate (NAR) within the period of 20-35, 35-50, 50-65 and 65-80 DAS in both the growing seasons. The highest NAR was observed in three irrigations (I_3) which differed significantly from the remaining treatments and the lowest value was found in rain-fed condition (I_0) in all the growing periods in both the years. NAR in both the varieties for irrigation levels increased slowly with fluctuations and showed highest NAR at 50-65 DAS and then declined rapidly. Similar result was reported by Yang *et al.* (1990) in barley. NAR fluctuated due to irrigation in both the years. Shivani *et al.* (2003) reported that higher NAR under four irrigations as compared to three and two irrigation treatments. Higher NAR due to higher soil moisture was found in beans (El-Nadi 1969 and Nerkar *et al.*, 1981). It is established that NAR became higher during the early vegetative stages and it declined rapidly as growth progressed (Koller *et al.*, 1970 and Haloi and Baldev 1986). This might be due to mutual shading of leaf and increases number of aged leaves which lost photosynthesis efficiency (Pandey *et al.*, 1978). Possibly decreased leaf area and increased photosynthesis resulted in the increase of NAR at the later stages of growth.

The effect of varieties on NAR of wheat at different growth stages are shown in Table 14a for 2014-15 and in Table 14b for 2015-16. Net assimilation rate (NAR) varied significantly at 50-65 and 65-80 DAS due to varieties in both the years. Within the period of 50-65 DAS

significantly higher NAR was observed in BARI Gom 24 (V_1) but within the period of 65-80 DAS the highest NAR was found in BARI Gom 26 (V_2) in both the growing seasons. Between the two varieties, BARI Gom 26 produced higher NAR than BARI Gom 24 in both the years.

Pattern of NAR for split applications of nitrogen with reference to their particular development stages are presented in Table 15a and Fig. 14a for first year (2014-15) and in Table 15b and Fig. 14b for second year (2015-16) respectively. Net assimilation rate (NAR) was significantly influenced by different split applications of nitrogen at most of the periods except 50-65 DAS in both the years. During 20-35 DAS, the highest NAR was observed in four split (N_3) applications of nitrogen which was statistically identical to three split (N_2) applications of nitrogen in both the years. At 35-50 DAS, the maximum NAR was obtained in three split (N_2) applications of nitrogen in both the growing seasons. During 65-80 DAS, the highest NAR was found in three split (N_2) applications of nitrogen which was statistically similar with four split (N_3) applications of nitrogen in both the years. In present study, NAR in both the varieties for split applications of nitrogen increased slowly with fluctuations and showed highest NAR at 50-65 DAS and then declined rapidly. Similar result was reported by Yang *et al.* (1990) in barley. NAR is an indirect photosynthetic activity. Ahmed and Farooq (2013) reported that the pattern of NAR was depended on the phenological stage at all sowing times, achieving maximum value at flag leaf stage and thereafter it declined sharply. Finally it reached negative values at later growth stages. The maximum NAR figure at flag leaf can be attributed by higher leaf area. Similar results were reported by Yang *et al.* (1990) in barley. Singh and Agarwal (2001) stated that the higher LAI and LAD attained through fertilization led to high photosynthetic efficiency, which contributed to higher NAR. Alam (2014) reported that the highest NAR was observed with the application of 160 kg N ha⁻¹ and the lowest one from the control. This might be due to maximum uptake of nitrogen and its use efficiency with more interception of solar radiation.

Different treatment combinations of irrigation and nitrogen had significant influenced on net assimilation rate (NAR) within the periods of 20-35, 35-50, 50-65 and 65-80 DAS in both the years under the present trail and are presented in Table 16a for first year (2014-15) and in Table 16b for second year (2015-16) respectively. From the table, it was observed that three irrigated plants (I_3) with three split applications of nitrogen (N_2) were produced the highest NAR at all growing periods followed by $I_3 \times N_3$ in both the years. With few exceptions, the lowest NAR was found in rain-fed crops with control at all growing periods in both the years.

4.1.8. Leaf area ratio (LAR)

Number of irrigation showed significant effect on leaf area ratio (LAR) with in the period of 20-35, 35-50, 50-65 and 65-80 DAS in both the years under the present study and are shown in Table 13a and Fig. 15a for first year (2014-15) and in Table 13b and Fig. 15b for second year (2015-16) respectively. At every stages of plant growth the highest LAR was obtained in the rain-fed (I_0) condition. During 20-35 and 35-50 DAS, the highest LAR was observed in rain-fed (I_0) condition which differed significantly from the remaining treatments in both the years. During 50-65 and 65-80 DAS, the highest LAR was observed in the rain-fed (I_0) condition in the first years (2014-15) and rain-fed (I_0) condition which was statistically identical to one (I_1) and two (I_2) irrigations in the second year (2015-16). The lowest values were found in three irrigations (I_3) at all growing periods in both the years. There was a decreasing trend of LAR with increasing number of irrigations. LAR value was higher at 20-35 DAS and decreased steadily with increasing plant age. It might be due to the abscission of mature and older leaves resulted in lower values of LAR at the later stages of growth. Similar results were reported in sugar beet, potato and barley by Thorne (1960), in black gram by Pandey *et al.* (1978), in rape by Murtaza and Paul (1986) and in wheat by Haque (1993), Rahman (1993) and Saha and Paul (1995). Haloi and Baldev (1986) also supported this and also in agreement with the result of the present investigation. Mollah and Paul (2007) reported that the rain-fed plants had higher LAR than the irrigated plant in barley. Similar results were reported by Nahar and Paul (1998) in wheat. Kingra and Mahey (2013) reported that LAR expresses the relationship between the leaf area and total respiring plant tissues. LAR was higher initially and it decreased with the crop growth as dry matter accumulation increase was higher.

Leaf area ratio (LAR) was significantly influenced due to varieties at 20-35, 35-50 and 50-65 DAS in both the growing seasons are presented in Table 14a for first year (2014-15) and in Table 14b for second year (2015-16) respectively. Within the periods of 20-35, 35-50 and 50-65 DAS significantly higher LAR was observed in BARI Gom 26 (V_2) in both the years. But during 65-80 DAS, the highest LAR was found in BARI Gom 26 in the second year (2015-16). LAR did not differ significantly in the first year (2014-15) during 65-80 DAS.

The effects of split applications of nitrogen on LAR at different growth stages are presented in Table 15a and Fig. 16a for first year (2014-15) and in Table 15b and Fig. 16b for second year (2015-16) respectively. Leaf area ratio (LAR) did not differ significantly within the period of 20-35, 35-50, 50-65 and 65-80 DAS in both the years. During 20-35 and 35-50

DAS, the highest values were obtained in basal (N_1) application of nitrogen and at 50-65 and 65-80 DAS; the highest values were found in three split (N_2) applications of nitrogen in both the years. LAR was higher during vegetative crop growth period and after that it declined steadily during rest of the growth period as after this period, leaf area index starts declining and partitioning of dry matter increases towards reproductive parts (Kingra and Mahey, 2013). LAR increased more or less with the increase of nitrogen application. This result indicated as nitrogen induces better plant growth and sustains physiological functions. Similar result was reported by Rahman (2004). In the present investigation, basal application of nitrogen produced the highest LAR at the early stages, but in later stages, three split applications of nitrogen produced the highest LAR in both the years (El-Hattab *et al.*, 1980). Alam (2014) stated that nitrogen level showed significant effect on LAR. The highest LAR was recorded from 160 kg N ha⁻¹ and the lowest in control. Amanullah *et al.* (2007) stated that the highest LAR was recorded in five split applications of nitrogen with greater proportion at later stages in maize.

Leaf area ratio (LAR) was significantly influenced by the interaction of number of irrigation and split applications of nitrogen within the period 20-35, 35-50, 50-65 and 65-80 DAS in both the growing seasons and are shown in Table 16a for first year (2014-15) and in Table 16b for second year (2015-16) respectively. During 20-35 and 35-50 DAS, the highest LAR was observed by the treatment combination of $I_0 \times N_1$ in both the growing seasons. Within the period of 50-65 and 65-80 DAS, the highest LAR was obtained by the treatment combination of $I_0 \times N_2$ in both the years. With few exceptions, the lowest LAR was obtained in $I_3 \times N_0$ at all growing periods in both the growing seasons.

Table 13a: Effect of irrigation on net assimilation rate and leaf area ratio of wheat (2014-15)

Irrigation	Net assimilation rate (mg cm ⁻² day ⁻¹)				Leaf area ratio (cm ² g ⁻¹)			
	20-35 DAS	35-50 DAS	50-65 DAS	65-80 DAS	20-35 DAS	35-50 DAS	50-65 DAS	65-80 DAS
I ₀	1.284 b	1.361 c	1.522 d	0.503 c	59.455 a	55.479 a	37.662 a	31.733 a
I ₁	1.310 b	1.380 b c	1.740 c	0.510 c	53.388 b	52.981 b	36.995 b	31.091 b
I ₂	1.330 b	1.422 b	1.867 b	0.535 b	50.520 bc	51.433 b	36.774 b	31.042 b
I ₃	1.398 a	1.551 a	2.039 a	0.561 a	48.080 c	47.511 c	34.258 c	30.021 c
CV (%)	2.748	3.160	4.710	7.057	7.102	5.096	4.672	3.789

At specific days after sowing, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

Table 13b: Effect of irrigation on net assimilation rate and leaf area ratio of wheat (2015-16)

Irrigation	Net assimilation rate (mg cm ⁻² day ⁻¹)				Leaf area ratio (cm ² g ⁻¹)			
	20-35 DAS	35-50 DAS	50-65 DAS	65-80 DAS	20-35 DAS	35-50 DAS	50-65 DAS	65-80 DAS
I ₀	1.338 b	1.368 c	1.509 c	0.450 d	59.312 a	54.702 a	36.560 a	31.207 a
I ₁	1.344 b	1.403 bc	1.737 b	0.476 c	53.136 b	52.437 b	36.342 a	30.893 a
I ₂	1.338 b	1.454 b	1.818 b	0.499 b	51.982 bc	51.339 b	36.220 a	31.026 a
I ₃	1.425 a	1.515 a	1.957 a	0.532 a	49.824 c	48.727 c	34.478 b	30.158 b
CV (%)	2.744	3.098	4.677	7.488	7.696	5.196	4.700	3.555

At specific days after sowing, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

Table 14a: Effect of variety on net assimilation rate and leaf area ratio of wheat (2014-15)

Variety	Net assimilation rate (mg cm ⁻² day ⁻¹)				Leaf area ratio (cm ² g ⁻¹)			
	20-35 DAS	35-50 DAS	50-65 DAS	65-80 DAS	20-35 DAS	35-50 DAS	50-65 DAS	65-80 DAS
V ₁	1.328 a	1.423 a	1.890 a	0.519 b	49.346 b	50.048 b	35.979 b	30.833 a
V ₂	1.334 a	1.434 a	1.694 b	0.536 a	56.376 a	53.654 a	36.866 a	31.110 a
CV (%)	2.748	3.160	4.710	7.057	7.102	5.096	4.672	3.789

At specific days after sowing, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

Table 14b: Effect of variety on net assimilation rate and leaf area ratio of wheat (2015-16)

Variety	Net assimilation rate (mg cm ⁻² day ⁻¹)				Leaf area ratio (cm ² g ⁻¹)			
	20-35 DAS	35-50 DAS	50-65 DAS	65-80 DAS	20-35 DAS	35-50 DAS	50-65 DAS	65-80 DAS
V ₁	1.358 a	1.430 a	1.851 a	0.482 b	50.006 b	50.005 b	35.463 b	30.632 b
V ₂	1.364 a	1.440 a	1.659 b	0.497 a	57.121 a	53.597 a	36.337 a	31.010 a
CV (%)	2.744	3.098	4.677	7.488	7.696	5.196	4.700	3.555

At specific days after sowing, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

Table 15a: Effect of nitrogen on net assimilation rate and leaf area ratio of wheat (2014-15)

Nitrogen	Net assimilation rate (mg cm ⁻² day ⁻¹)				Leaf area ratio (cm ² g ⁻¹)			
	20-35 DAS	35-50 DAS	50-65 DAS	65-80 DAS	20-35 DAS	35-50 DAS	50-65 DAS	65-80 DAS
N ₀	1.200 c	1.459 ab	1.727 a	0.504 b	52.044 a	50.348 a	35.733 a	30.809 a
N ₁	1.312 b	1.363 c	1.793 a	0.514 b	53.754 a	52.448 a	36.593 a	30.949 a
N ₂	1.391 a	1.494 a	1.843 a	0.546 a	52.539 a	52.428 a	36.764 a	31.145 a
N ₃	1.419 a	1.398 bc	1.806 a	0.545 a	53.107 a	52.181 a	36.599 a	30.984 a
CV (%)	2.748	3.160	4.710	7.057	7.102	5.096	4.672	3.789

At specific days after sowing, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

Table 15b: Effect of nitrogen on net assimilation rate and leaf area ratio of wheat (2015-16)

Nitrogen	Net assimilation rate (mg cm ⁻² day ⁻¹)				Leaf area ratio (cm ² g ⁻¹)			
	20-35 DAS	35-50 DAS	50-65 DAS	65-80 DAS	20-35 DAS	35-50 DAS	50-65 DAS	65-80 DAS
N ₀	1.229 c	1.466 ab	1.689 a	0.468 b	52.741 a	50.304 a	35.221 a	30.656 a
N ₁	1.342 b	1.369 b	1.757 a	0.475 b	54.467 a	52.402 a	36.066 a	30.801 a
N ₂	1.423 a	1.501 a	1.805 a	0.507 a	53.815 a	52.362 a	36.239 a	30.984 a
N ₃	1.452 a	1.404 b	1.769 a	0.506 a	53.232 a	52.136 a	36.074 a	30.842 a
CV (%)	2.744	3.098	4.677	7.488	7.696	5.196	4.700	3.555

At specific days after sowing, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

Table 16a: Interaction effect of irrigation and nitrogen on net assimilation rate and leaf area ratio of wheat (2014-15)

Interaction (Irrigation × Nitrogen)	Net assimilation rate (mg cm ⁻² day ⁻¹)				Leaf area ratio (cm ² g ⁻¹)			
	20-35 DAS	35-50 DAS	50-65 DAS	65-80 DAS	20-35 DAS	35-50 DAS	50-65 DAS	65-80 DAS
I ₀ N ₀	1.147 l	1.493 c	1.369 g	0.491 fg	57.345 a-d	54.953 a-c	36.990 a-d	30.887 de
I ₀ N ₁	1.259 i	1.299 h	1.533 fg	0.478 g	61.790 a	56.930 a	37.887 ab	31.537 bc
I ₀ N ₂	1.354 f	1.401 e	1.613 d-g	0.530 de	58.709 a-c	54.260 a-c	37.970 a	33.008 a
I ₀ N ₃	1.376 e	1.327 g	1.572 e-g	0.512 ef	59.975 ab	55.773 ab	37.803 ab	31.499 bc
I ₁ N ₀	1.173 k	1.406 e	1.591 d-g	0.482 g	55.256 a-e	54.622 a-c	37.509 a-c	31.834 b
I ₁ N ₁	1.293 gh	1.279 i	1.776 c-f	0.488 fg	53.288 b-f	53.257 a-d	37.323 a-d	31.132 cd
I ₁ N ₂	1.374 ef	1.447 d	1.817 b-e	0.538 cd	51.886 b-f	50.710 c-f	35.797 ef	30.543 ef
I ₁ N ₃	1.397 d	1.313 gh	1.779 c-f	0.530 de	53.122 b-f	53.336 a-d	37.352 a-d	30.854 de
I ₂ N ₀	1.198 j	1.399 e	1.820 b-d	0.502 fg	50.755 c-f	52.891 a-d	37.481 a-c	30.948 de
I ₂ N ₁	1.313 g	1.371 f	1.867 bc	0.528 de	50.931 c-f	51.563 b-e	36.813 b-e	30.980 de
I ₂ N ₂	1.382 de	1.501 c	1.909 a-c	0.552 b-d	49.792 d-f	49.841 d-f	36.245 de	31.628 b
I ₂ N ₃	1.429 c	1.417 e	1.870 bc	0.559 a-c	50.603 c-f	51.438 b-e	36.556 c-e	30.613 ef
I ₃ N ₀	1.282 h	1.538 b	2.001 a-c	0.542 b-d	46.799 f	46.580 f	33.900 g	28.789 g
I ₃ N ₁	1.381 de	1.502 c	1.996 a-c	0.561 a-c	49.007 ef	48.177 ef	34.348 g	30.149 f
I ₃ N ₂	1.475 a	1.629 a	2.130 a	0.578 a	47.786 ef	47.245 ef	34.097 g	30.878 de
I ₃ N ₃	1.454 b	1.534 b	2.031 ab	0.564 ab	48.727 ef	48.041 ef	34.685 fg	30.270 f
CV (%)	2.748	3.160	4.710	7.057	7.102	5.096	4.672	3.789

At specific days after sowing, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

Table 16b: Interaction effect of irrigation and nitrogen on net assimilation rate and leaf area ratio of wheat (2015-16)

Interaction (Irrigation × Nitrogen)	Net assimilation rate (mg cm ⁻² day ⁻¹)				Leaf area ratio (cm ² g ⁻¹)			
	20-35 DAS	35-50 DAS	50-65 DAS	65-80 DAS	20-35 DAS	35-50 DAS	50-65 DAS	65-80 DAS
I ₀ N ₀	1.202 g	1.517 bc	1.356 f	0.444 ij	57.207 a-d	54.181 a-c	36.878 a	32.461 a
I ₀ N ₁	1.319 f	1.321 i	1.522 ef	0.425 j	61.642 a	56.134 a	36.771 ab	31.012 c
I ₀ N ₂	1.417 cd	1.424 f	1.601 c-e	0.475 gh	58.569 a-c	53.498 a-e	35.901 a-d	30.378 ef
I ₀ N ₃	1.440 b	1.349 h	1.560 d-f	0.458 hi	59.831 ab	54.994 ab	36.69 ab	30.977 cd
I ₁ N ₀	1.198 g	1.414 fg	1.586 c-f	0.452 i	54.996 a-e	54.055 a-d	36.855 a	31.627 b
I ₁ N ₁	1.322 f	1.285 j	1.772 b-d	0.454 hi	53.037 b-e	52.714 a-f	36.662 ab	30.934 c-e
I ₁ N ₂	1.404 de	1.454 d	1.813 a-c	0.503 d-f	51.64 b-e	50.188 c-g	35.162 c-e	30.349 f
I ₁ N ₃	1.427 bc	1.319 i	1.775 b-d	0.496 e-g	52.874 b-e	52.789 a-f	36.69 ab	30.66 c-f
I ₂ N ₀	1.204 g	1.430 ef	1.772 b-d	0.466 hi	52.227 b-e	52.778 a-f	36.913 a	30.933 c-e
I ₂ N ₁	1.321 f	1.403 g	1.818 a-c	0.491 fg	52.402 b-e	51.477 b-g	36.257 a-c	30.971 cd
I ₂ N ₂	1.390 e	1.534 b	1.859 ab	0.516 b-e	51.235 c-e	49.752 d-g	35.701 b-d	31.623 b
I ₂ N ₃	1.438 b	1.449 de	1.821 a-c	0.522 b-d	52.063 b-e	51.347 b-g	36.007 a-d	30.578 c-f
I ₃ N ₀	1.310 f	1.504 c	1.915 ab	0.511 c-f	48.497 e	48.434 fg	34.310 e	28.916 g
I ₃ N ₁	1.408 c-e	1.467 d	1.920 ab	0.531 a-c	50.788 c-e	49.283 e-g	34.573 e	30.287 f
I ₃ N ₂	1.501 a	1.591 a	2.044 a	0.549 a	49.522 de	47.777 g	34.12 e	31.019 c
I ₃ N ₃	1.481 ab	1.499 c	1.949 ab	0.535 ab	50.491 c-e	49.413 e-g	34.909 de	30.409 d-f
CV (%)	2.744	3.098	4.677	7.488	7.696	5.196	4.700	3.555

At specific days after sowing, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

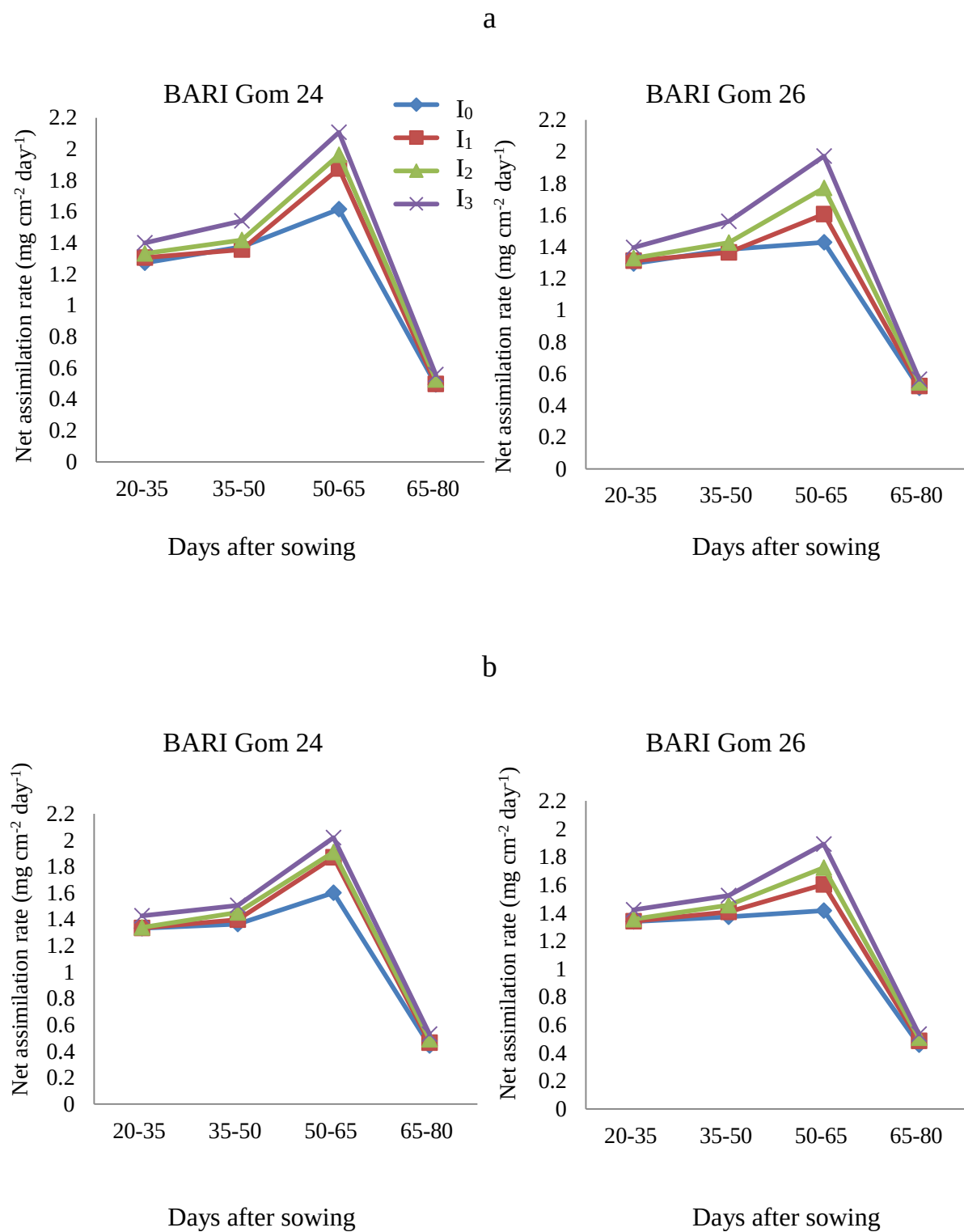


Fig. 13 Effect of irrigation on net assimilation rate at different days after sowing in 2014-15(a) and 2015-16(b)

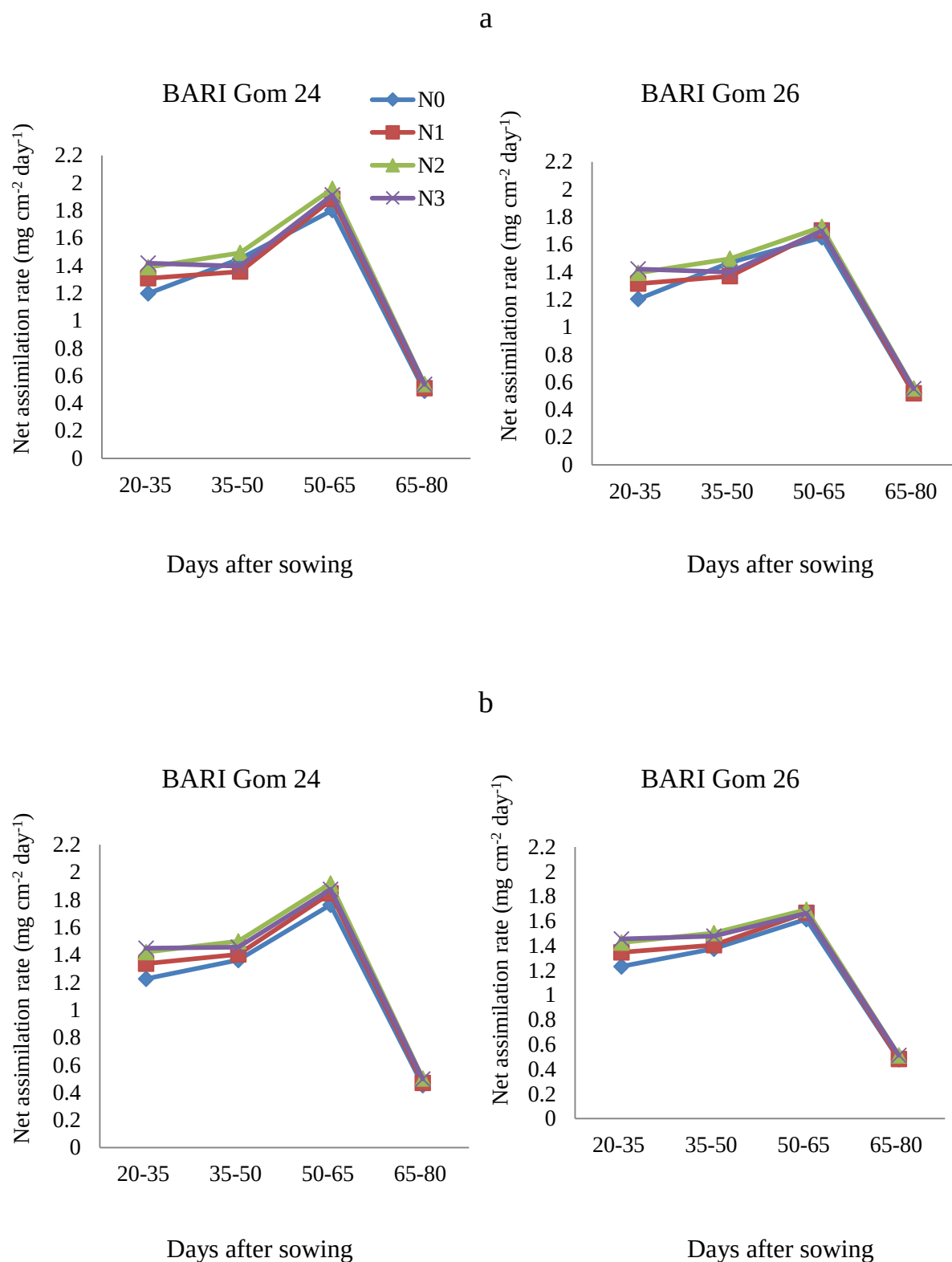


Fig. 14 Effect of nitrogen on net assimilation rate at different days after sowing in 2014-15(a) and 2015-16(b)

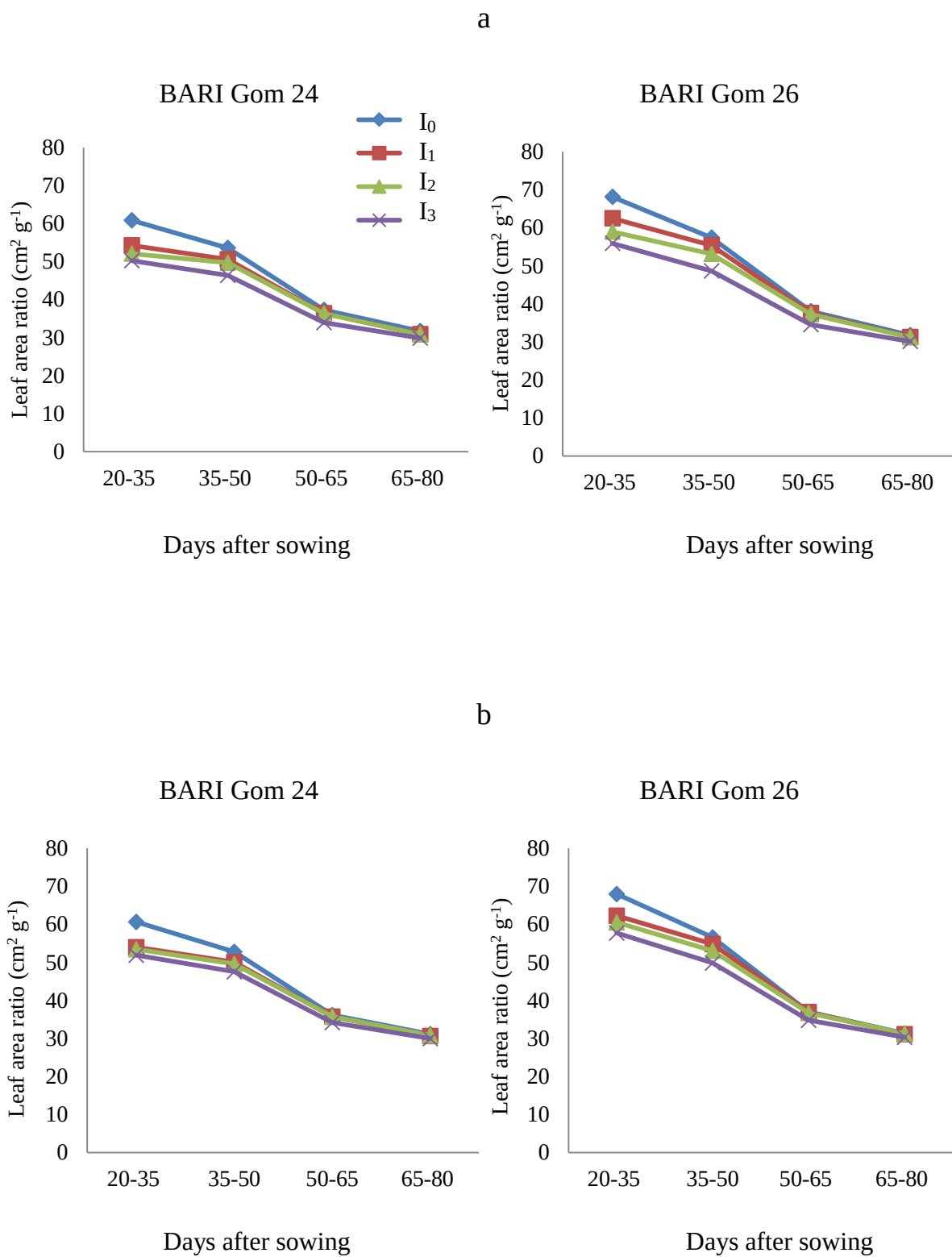


Fig. 15 Effect of irrigation on leaf area ratio at different days after sowing in 2014-15(a) and 2015-16(b)

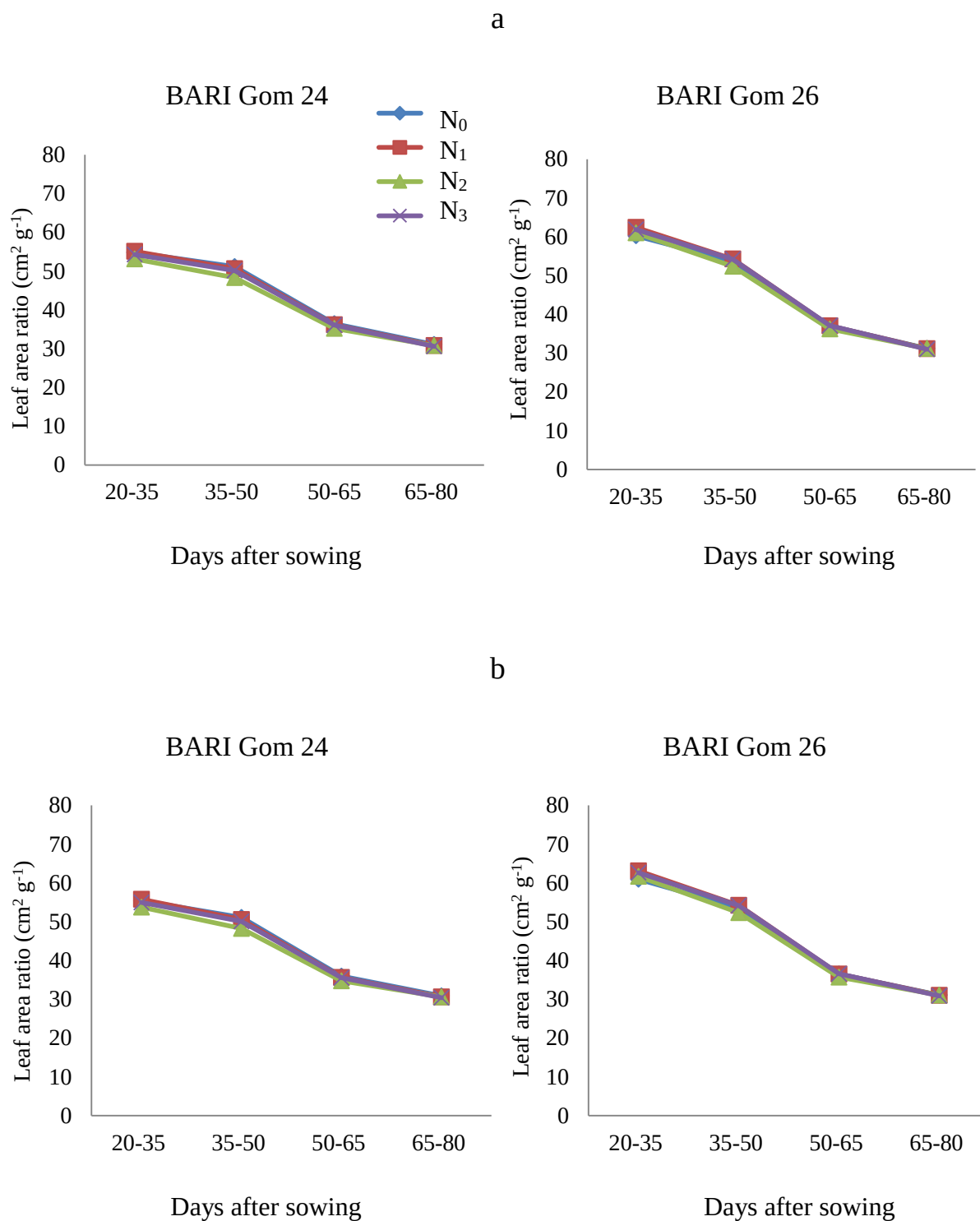


Fig. 16 Effect of nitrogen on leaf area ratio at different days after sowing in 2014-15(a) and 2015-16(b)

4.1.9. Relative leaf growth rate (RLGR)

There was significant effect of irrigation levels on relative leaf growth rate (RLGR) during 20-35, 35-50 and 65-80 DAS in both the years and are presented in Table 17a and Fig. 17a for first year (2014-15) and in Table 17b and Fig. 17b for second year (2015-16) respectively. During 20-35 DAS, the highest RLGR was observed in one (I_1), two (I_2) and three (I_3) irrigations in the first year (2014-15) and one (I_1) and two (I_2) irrigations which was statistically identical to three (I_3) irrigations in the second year (2015-16). Within the period of 35-50 DAS, the highest RLGR was obtained in two (I_2) and three (I_3) irrigations in both the growing seasons. RLGR did not differ significantly within the period of 50-65 DAS in both the years. During 65-80 DAS, the highest RLGR was found in three (I_3) irrigations followed by two (I_2) and one (I_1) irrigation in both the years. RLGR values were found to be increased with increasing irrigation levels in both the years. In the present investigation, RLGR values were found to decrease with increasing plant age. Similar result was reported by Mondal and Paul (1992), Khan and Paul (1993), Rahman (1993), Saha and Paul (1995), Sarker and Paul (1998) and Sarker *et al.* (1996) in wheat. The cause of decline of RLGR at the later stages was due to abscission of older leaves. It was also observed that high temperature at the later stages of growth accelerated the abscission of old leaves. The abscission of old leaves resulted in the decline of RLGR at the later stages of growth (Pandey *et al* 1978). Comparatively higher RLGR was found in the irrigated plants than in non-irrigated plants (Sarker and Paul 1998, Sarker *et al.*, 1996 and Saha and Paul 1995).

Varieties had no significant effect on RLGR during all growing periods in both the years and are shown in Table 18a for first year (2014-15) and in Table 18b for second year (2015-16) respectively. Between the two varieties, BARI Gom 24 produced higher RLGR than BARI Gom 26 in both the years.

The effects of split applications of nitrogen on relative leaf growth rate (RLGR) of wheat are presented in Table 19a and Fig. 18a for first year (2014-15) and in Table 19b and Fig. 18b for second year (2015-16) respectively. Split applications of nitrogen had significant effect on relative leaf growth rate (RLGR) during 20-35, 35-50, 50-65 and 65-80 DAS in both the years. During 20-35 DAS, all the nitrogen treatments except control (N_0) gave statistically similar RLGR and the lowest RLGR was observed in control (N_0) in both the years. During 35-50 and 65-80 DAS the highest RLGR was recorded in three split (N_2) applications of nitrogen followed by basal (N_1) and four (N_3) split applications of nitrogen and the lowest value was observed in control (N_0) in both the growing seasons. Within the period of 50-65

DAS three (N_2) and four (N_3) split applications of nitrogen gave the highest RLGR followed by basal (N_1) application of nitrogen and the lowest value was found in control (N_0). This result is in agreement with that of wheat (Rahman, 2004).

Relative leaf growth rate (RLGR) was significantly influenced by the interaction of irrigation and nitrogen during 20-35, 35-50, 50-65 and 65-80 DAS in both the years and are shown in Table 20a for first year (2014-15) and in Table 20b for second year (2015-16) respectively. During 20-35 DAS, all irrigated plants with nitrogen fertilization ($I_1 \times N_1$, $I_1 \times N_2$, $I_1 \times N_3$, $I_2 \times N_1$, $I_2 \times N_2$, $I_2 \times N_3$, $I_3 \times N_1$, $I_3 \times N_2$ and $I_3 \times N_3$) were produced statistically similar RLGR and the lowest value was found in $I_0 \times N_0$ in both the years. During 35-50 and 50-65 DAS, the treatment combinations $I_2 \times N_2$ and $I_3 \times N_2$ were given the highest RLGR and the lowest was found in $I_0 \times N_0$ in both the years. During 65-80 DAS, the treatment combinations of $I_3 \times N_2$ were given the highest RLGR and the lowest value was found in $I_0 \times N_0$ in both the growing seasons.

4.1.10. Specific leaf area (SLA)

The effect of irrigation treatments on specific leaf area (SLA) at different growth stages are presented in Table 17a and Fig. 19a for first year (2014-15) and in Table 17b and Fig. 19b for second year (2015-16) respectively. Irrigation levels showed significant effects on specific leaf area (SLA) at all the growing periods in both the years. In case of all growing periods, the highest SLA was observed in rain-fed condition (I_0) followed by one (I_1) and two (I_2) irrigation and the lowest SLA was found in three irrigations (I_3) in both the years. In both the irrigated and rain-fed conditions, all the varieties had generally higher SLA at the early stage of growth. The decline of SLA with increasing plant age was noticed in rape and turnip by Paul (1980), in jute by Saha (1983), in pearl millet by Chanda *et al.* (1987) and in wheat by Rahman (1993), Saha and Paul (1995) and Sarker and Paul (1998). The rain-fed plants showed higher SLA. Similar result was reported in wheat (Sarker and Paul, 1998). Zaman (2016) stated that the higher SLA was observed in water deficit condition than control in wheat (no water stress).

There was significant effect of variety on specific leaf area (SLA) at most of the growing periods except at 65-80 DAS are presented in Table 18a for first year (2014-15) and in Table 18b for second year (2015-16) respectively. Within the periods of 20-35, 35-50 and 50-65 DAS, BARI Gom 26 (V_2) showed significantly higher SLA compared to BARI Gom 24 (V_1) in both the years.

Specific leaf area (SLA) is a measure of leaf thickness. Significant variation was observed in case of specific leaf area (SLA) with split applications of nitrogen during 50-65 and 65-80 DAS in both the years and it is presented in Table 19a and Fig. 20a for first year (2014-15) and in Table 19b and Fig. 20b for second year (2015-16) respectively. SLA values decreased with increasing plant dry weight was observed by Chanda *et al.* (1987) in pearl miller. Within the period of 20-35 and 35-50 DAS, SLA did not differ significantly in both the years. During 50-65 and 65-80 DAS, all the nitrogen treatment except control (N_0) produced statistically similar SLA and the lowest SLA was observed in control (N_0) in both the years. Alam (2014) stated that nitrogen level showed significant effect on SLA. The highest SLA was recorded from 160 kg N ha⁻¹ and the lowest in control. Amanullah *et al.* (2007) stated that the highest SLA was recorded in five split application of nitrogen with greater proportion at later stages in maize. It was revealed from the present study the SLA increased with the increase of nitrogen fertilization.

Different treatment combinations of irrigation and nitrogen had significant influenced on specific leaf area (SLA) of wheat at all the growing periods in both the years and are shown in Table 20a for first year (2014-15) and in Table 20b for second year (2015-16) respectively. Within the period of 20-35 and 35-50 DAS, the maximum SLA was achieved by the treatment combination of $I_0 \times N_1$ in both the years. During 50-65 DAS, the highest SLA was observed in treatment combination of $I_0 \times N_1$ in both the years followed by $I_0 \times N_3$ in the second year (2015-16). Within the period of 65-80 DAS, the highest SLA was recorded in $I_0 \times N_3$ in both the years followed by $I_0 \times N_1$ in the first year (2014-15). The lowest SLA was found in $I_3 \times N_0$ at all growing periods in both the years.

Table 17 a: Effect of irrigation on relative leaf growth rate and specific leaf area of wheat (2014-15)

Irrigation	Relative leaf growth rate (cm ² cm ⁻² day ⁻¹)				Specific leaf area (cm ² g ⁻¹)			
	20-35 DAS	35-50 DAS	50-65 DAS	65-80 DAS	20-35 DAS	35-50 DAS	50-65 DAS	65-80 DAS
I ₀	0.135 b	0.040 b	0.030 a	0.010 c	107.229 a	128.198 a	108.853 a	100.187 a
I ₁	0.140 a	0.041 b	0.029 a	0.010 c	95.218 b	118.326 b	102.796 b	93.388 b
I ₂	0.140 a	0.046 a	0.029 a	0.012 b	88.683 c	114.867 b	102.673 b	92.266 b
I ₃	0.140 a	0.046 a	0.029 a	0.016 a	83.935 c	105.978 c	95.869 c	90.286 b
CV (%)	5.768	2.861	1.483	3.583	7.299	8.409	9.114	8.123

At specific days after sowing, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

Table 17 b: Effect of irrigation management on relative leaf growth rate and specific leaf area of wheat (2015-16)

Irrigation	Relative leaf growth rate (cm ² cm ⁻² day ⁻¹)				Specific leaf area (cm ² g ⁻¹)			
	20-35 DAS	35-50 DAS	50-65 DAS	65-80 DAS	20-35 DAS	35-50 DAS	50-65 DAS	65-80 DAS
I ₀	0.135 b	0.038 b	0.030 a	0.010 c	107.215 a	127.451 a	106.831 a	98.183 a
I ₁	0.140 a	0.040 b	0.029 a	0.011 bc	94.238 b	117.031 b	101.561 b	92.537 b
I ₂	0.140 a	0.045 a	0.029 a	0.012 b	92.169 bc	114.777 b	100.362 b	91.864 b
I ₃	0.139 a	0.045 a	0.030 a	0.016 a	88.044 c	108.527 c	95.628 c	90.454 b
CV (%)	5.843	2.934	1.451	2.544	18.489	17.182	9.049	8.016

At specific days after sowing, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

Table 18 a: Effect of variety on relative leaf growth rate and specific leaf area of wheat (2014-15)

Variety	Relative leaf growth rate ($\text{cm}^2 \text{ cm}^{-2} \text{ day}^{-1}$)				Specific leaf area ($\text{cm}^2 \text{ g}^{-1}$)			
	20-35 DAS	35-50 DAS	50-65 DAS	65-80 DAS	20-35 DAS	35-50 DAS	50-65 DAS	65-80 DAS
V ₁	0.139 a	0.043 a	0.029 a	0.012 a	88.069 b	111.026 b	99.362 b	92.777 a
V ₂	0.138 a	0.043 a	0.029 a	0.012 a	99.463 a	122.659 a	105.733 a	95.286 a
CV (%)	5.768	2.861	1.483	3.583	7.299	8.409	9.114	8.123

At specific days after sowing, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

Table 18 b: Effect of variety on relative leaf growth rate and specific leaf area of wheat (2015-16)

Variety	Relative leaf growth rate ($\text{cm}^2 \text{ cm}^{-2} \text{ day}^{-1}$)				Specific leaf area ($\text{cm}^2 \text{ g}^{-1}$)			
	20-35 DAS	35-50 DAS	50-65 DAS	65-80 DAS	20-35 DAS	35-50 DAS	50-65 DAS	65-80 DAS
V ₁	0.139 a	0.042 a	0.030 a	0.012 a	89.608 b	111.124 b	97.956 b	91.871 a
V ₂	0.138 a	0.042 a	0.030 a	0.012 a	101.226 a	122.769 a	104.235 a	94.648 a
CV (%)	5.843	2.934	1.451	2.544	18.489	17.182	9.049	8.016

At specific days after sowing, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

Table 19 a: Effect of nitrogen on relative leaf growth rate and specific leaf area of wheat (2014-15)

Nitrogen	Relative leaf growth rate (cm ² cm ⁻² day ⁻¹)				Specific leaf area (cm ² g ⁻¹)			
	20-35 DAS	35-50 DAS	50-65 DAS	65-80 DAS	20-35 DAS	35-50 DAS	50-65 DAS	65-80 DAS
N ₀	0.129 b	0.039 c	0.020 c	0.010 b	91.891 a	116.757 a	95.574 b	82.931 b
N ₁	0.142 a	0.042 b	0.030 b	0.010 b	95.112 a	118.571 a	106.277 a	97.936 a
N ₂	0.142 a	0.051 a	0.034 a	0.015 a	93.621 a	114.091 a	102.581 a	97.792 a
N ₃	0.142 a	0.042 b	0.034 a	0.012 ab	94.440 a	117.951 a	105.757 a	97.468 a
CV (%)	5.768	2.861	1.483	3.583	7.299	8.409	9.114	8.123

At specific days after sowing, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

Table 19 b: Effect of nitrogen on relative leaf growth rate and specific leaf area of wheat (2015-16)

Nitrogen	Relative leaf growth rate (cm ² cm ⁻² day ⁻¹)				Specific leaf area (cm ² g ⁻¹)			
	20-35 DAS	35-50 DAS	50-65 DAS	65-80 DAS	20-35 DAS	35-50 DAS	50-65 DAS	65-80 DAS
N ₀	0.129 b	0.038 c	0.021 c	0.010 c	93.515 a	114.777 a	94.200 b	82.271 b
N ₁	0.142 a	0.041 b	0.030 b	0.011 b	96.780 a	118.699 a	104.782 a	97.123 a
N ₂	0.141 a	0.049 a	0.034 a	0.016 a	95.268 a	116.231 a	101.136 a	97.006 a
N ₃	0.141 a	0.040 b	0.034 a	0.012 ab	96.103 a	118.079 a	104.266 a	96.638 a
CV (%)	5.843	2.934	1.451	2.544	18.489	17.182	9.049	8.016

At specific days after sowing, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

Table 20 a: Interaction effect of irrigation and nitrogen on relative leaf growth rate and specific leaf area of wheat (2014-15)

Interaction (Irrigation × Nitrogen)	Relative leaf growth rate (cm ² cm ⁻² day ⁻¹)				Specific leaf area (cm ² g ⁻¹)			
	20-35 DAS	35-50 DAS	50-65 DAS	65-80 DAS	20-35 DAS	35-50 DAS	50-65 DAS	65-80 DAS
I ₀ N ₀	0.123 e	0.035 h	0.024 f	0.015 c	102.896 a-d	123.606 a-c	99.020 d-f	90.790 f
I ₀ N ₁	0.141 b	0.038 f	0.029 e	0.008 h	111.406 a	133.094 a	113.749 a	103.700 a
I ₀ N ₂	0.139 bc	0.048 b	0.033 c	0.008 h	105.982 a-c	126.573 a-c	109.841 a-c	102.225 ab
I ₀ N ₃	0.139 bc	0.037 g	0.034 b	0.008 h	108.631 ab	129.519 ab	112.800 ab	104.032 a
I ₁ N ₀	0.131 d	0.037 g	0.020 g	0.015 c	99.309 a-e	122.259 a-d	95.947 e-g	81.428 g
I ₁ N ₁	0.143 a	0.040 e	0.030 d	0.008 h	94.717 b-f	118.329 a-f	106.312 a-d	98.568 bc
I ₁ N ₂	0.142 a	0.048 b	0.033 c	0.010 f	91.804 c-f	113.563 c-f	102.369 c-f	95.982 c-e
I ₁ N ₃	0.142 a	0.040 e	0.033 c	0.009 g	95.041 b-f	119.153 a-e	106.556 a-d	97.574 cd
I ₂ N ₀	0.132 d	0.042 d	0.018 h	0.015 c	90.156 d-f	117.952 a-f	98.110 d-f	80.872 g
I ₂ N ₁	0.143 a	0.045 c	0.030 d	0.010 f	89.136 d-f	114.837 b-f	105.807 a-d	95.912 c-e
I ₂ N ₂	0.143 a	0.054 a	0.035 a	0.013 d	86.660 ef	111.616 c-f	102.331 c-f	97.717 cd
I ₂ N ₃	0.143 a	0.044 c	0.033 c	0.011 e	88.780 d-f	115.064 b-f	104.444 b-e	94.562 d-f
I ₃ N ₀	0.131 d	0.042d	0.018 h	0.016 b	82.125 f	103.211 f	89.220 g	78.632 g
I ₃ N ₁	0.142 a	0.045 c	0.030 d	0.015 c	85.189 ef	108.024 d-f	99.239 d-f	93.563 ef
I ₃ N ₂	0.143 a	0.054 a	0.035 a	0.018 a	83.119 f	104.611 ef	95.785 fg	95.245 c-e
I ₃ N ₃	0.142 a	0.045 c	0.034 b	0.015 c	85.309 ef	108.066 d-f	99.230 d-f	93.704 ef
CV (%)	5.768	2.861	1.483	3.583	7.299	8.409	9.114	8.123

At specific days after sowing, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

Table 20 b: Interaction effect of irrigation and nitrogen on relative leaf growth rate and specific leaf area of wheat (2015-16)

Interaction (Irrigation × Nitrogen)	Relative leaf growth rate (cm ² cm ⁻² day ⁻¹)				Specific leaf area (cm ² g ⁻¹)			
	20-35 DAS	35-50 DAS	50-65 DAS	65-80 DAS	20-35 DAS	35-50 DAS	50-65 DAS	65-80 DAS
I ₀ N ₀	0.122 e	0.034 g	0.025 g	0.015 c	102.883 a-c	122.881 a-c	97.227 c-f	89.011 e
I ₀ N ₁	0.140 b	0.037 e	0.029 f	0.008 h	111.392 a	132.323 a	111.627 a	101.613 ab
I ₀ N ₂	0.139 bc	0.047 b	0.033 c	0.008 h	105.969 ab	125.835 a-c	107.786 ab	100.174 a-c
I ₀ N ₃	0.138 c	0.036 f	0.034 b	0.008 h	108.617 ab	128.765 ab	110.686 a	101.935 a
I ₁ N ₀	0.131 d	0.036 f	0.021 h	0.016 b	98.288 a-d	120.921 a-d	94.803 ef	80.706 f
I ₁ N ₁	0.143 a	0.039 d	0.030 e	0.009 g	93.742 b-d	117.034 a-d	105.032 a-c	97.665 b-d
I ₁ N ₂	0.142 a	0.046 b	0.033 c	0.010 f	90.859 cd	112.320 cd	101.135 b-e	95.098 d
I ₁ N ₃	0.142 a	0.039 d	0.033 c	0.009 g	94.063 b-d	117.849 a-d	105.274 a-c	96.679 cd
I ₂ N ₀	0.131 d	0.040 d	0.018 i	0.015 c	93.751 b-d	117.727 a-d	95.768 d-f	80.568 f
I ₂ N ₁	0.142 a	0.043 c	0.030 e	0.010 g	92.627 b-d	114.790 b-d	103.479 a-d	95.491 d
I ₂ N ₂	0.143 a	0.052 a	0.035 a	0.013 d	90.049 cd	111.583 cd	100.078 b-e	97.323 cd
I ₂ N ₃	0.142 a	0.043 c	0.033 c	0.011 e	92.251 b-d	115.007 b-d	102.124 b-e	94.075 d
I ₃ N ₀	0.131 d	0.041 d	0.019 i	0.016 b	86.151 d	105.579 d	89.000 f	78.798 f
I ₃ N ₁	0.142 a	0.043 c	0.031 d	0.015 c	89.358 cd	110.649 cd	98.989 c-e	93.724 d
I ₃ N ₂	0.142 a	0.052 a	0.035 a	0.018 a	87.185 d	107.186 d	95.543 d-f	95.429 d
I ₃ N ₃	0.142 a	0.043 c	0.034 b	0.015 c	89.483 cd	110.693 cd	98.980 c-e	93.865 d
CV (%)	5.843	2.934	1.451	2.544	18.489	17.182	9.049	8.016

At specific days after sowing, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

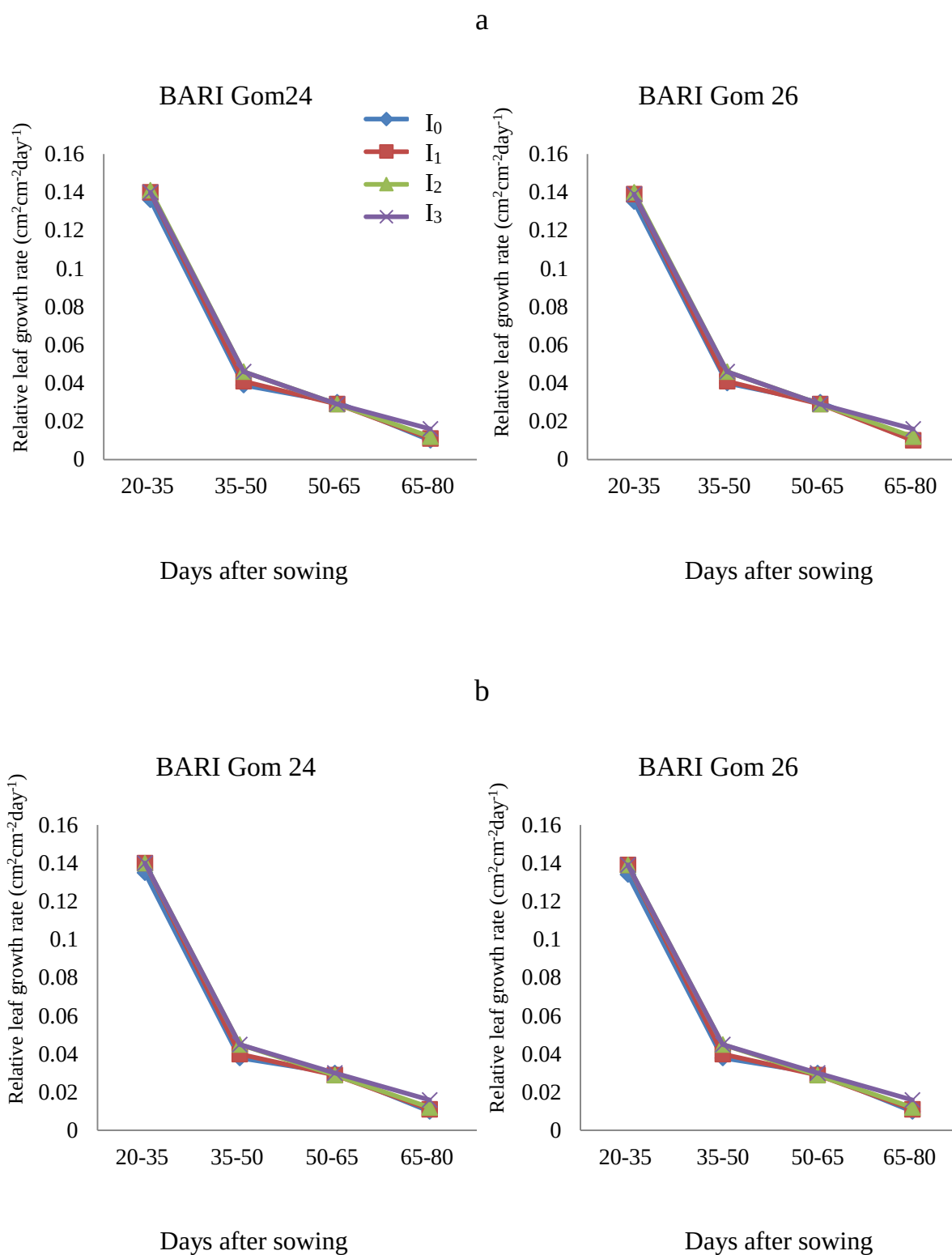
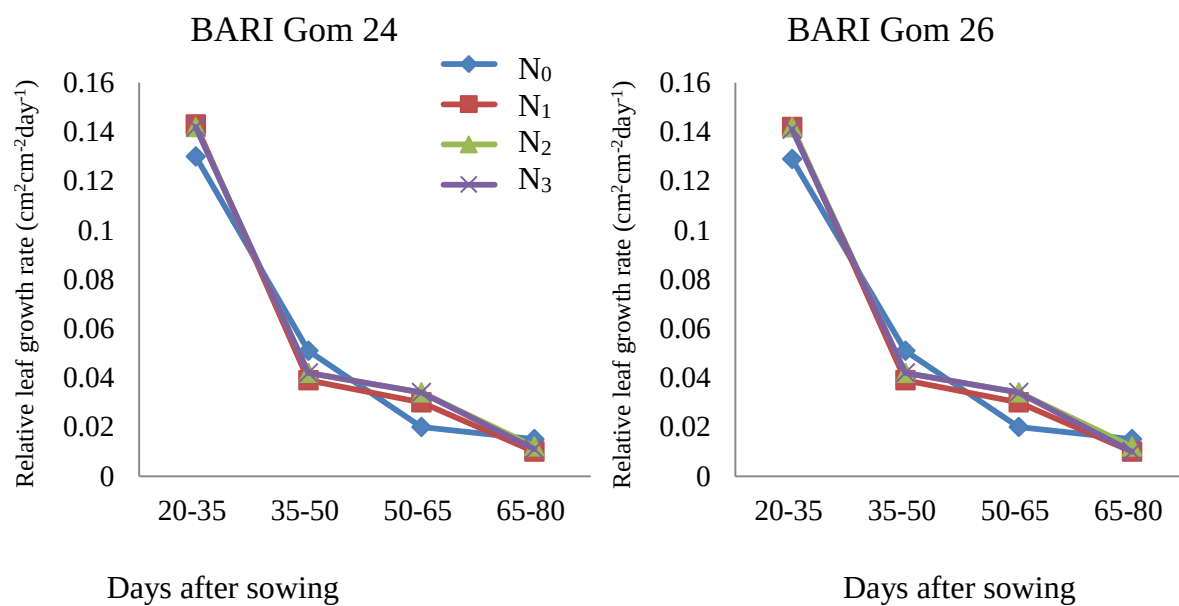


Fig. 17 Effect of irrigation on relative leaf growth rate at different days after sowing in 2014-15(a) and 2015-16(b)

a



b

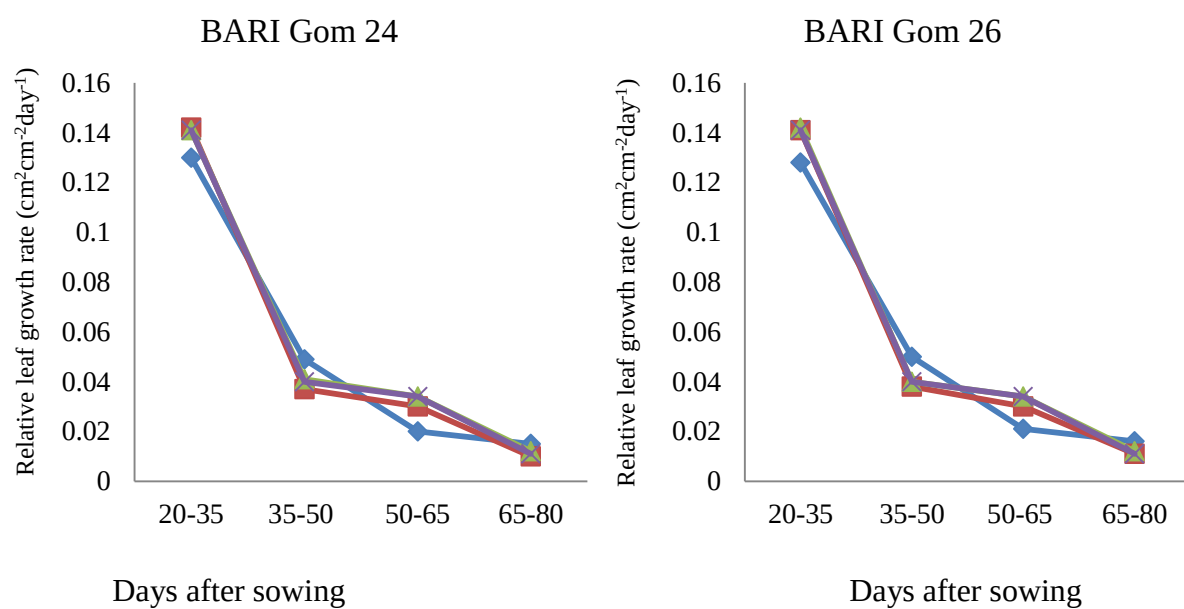


Fig. 18 Effect of nitrogen on relative leaf growth rate at different days after sowing in 2014-15(a) and 2015-16(b)

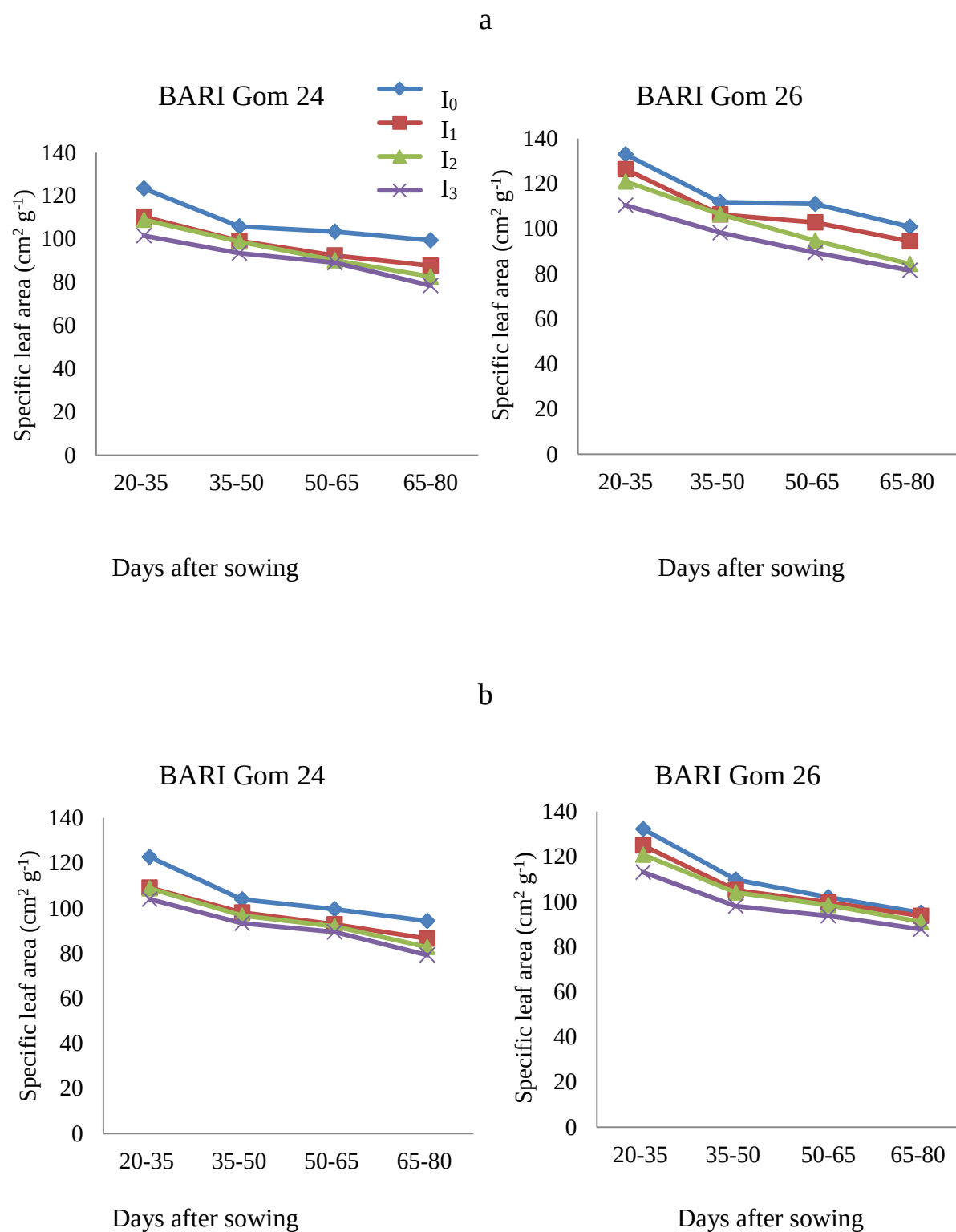


Fig. 19 Effect of irrigation on specific leaf area at different days after sowing in 2014-15(a) and 2015-16(b)

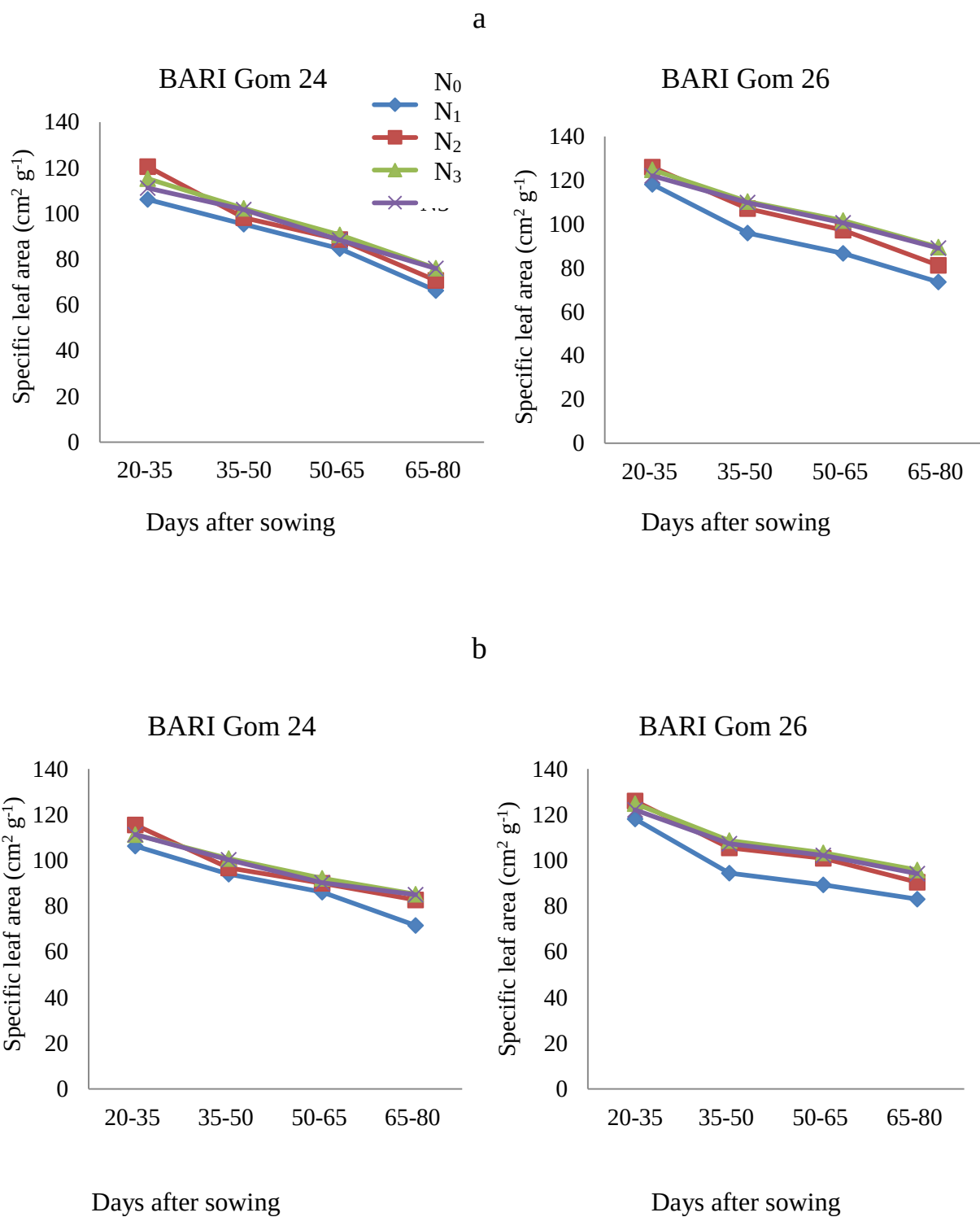


Fig. 20 Effect of nitrogen on specific leaf area at different days after sowing in 2014-15(a) and 2015-16(b)

4.1.11. Leaf weight ratio (LWR)

The effect of irrigation on leaf weight ratio (LWR) at different growth stages and are presented in Table 21a and Fig. 21a for first year (2014-15) and in Table 21b and Fig. 21b for second year (2015-16) respectively. Leaf weight ratio (LWR) varied significantly at 20-35 and 35-50 in the first year (2014-15) and all growth periods in the second year (2015-16) due to irrigation treatments. During 20-35 and 35-50 DAS, two (I_2) and three (I_3) irrigations in the first year (2014-15) and one (I_1), two (I_2) and three (I_3) irrigations in second year (2015-16) were given statistically similar LWR and the lowest LWR was obtained in rain-fed crops (I_0) in both the years. During the period of 65-80 DAS, the highest LWR was found in two irrigations (I_2) followed by one (I_1) and three (I_3) irrigations and the lowest LWR was observed in rain-fed (I_0) condition in both the years. Within the period of 65-80 DAS, the highest LWR was recorded in two irrigations (I_2) and the lowest LWR was found in rain-fed (I_0) condition in both the growing seasons. The highest values of LWR were found in irrigated plants. Similar result was also found in wheat (Sarker and Paul 1998, Simane *et al.*, 1993 and Saha and Paul 1995). The increased of LWR in the irrigated plants might be due to increase leaf weight. The values of LWR showed downward drifts with age. Saha and Paul (1995) studied LWR in wheat and reported that the sharp decrease in LWR at the later stages might be due to the sharp increase of TDM. The decline of LWR with age was also observed in wheat (Rahman, 1993). This result was also supported by Thorne (1960) and Rahman (2004) in wheat and Bahadur (2008) in barley.

LWR varied significantly due to varieties during 35-50 and 50-65 DAS while LWR did not differ significantly within the periods of 20-35 and 65-80 DAS in both the years and are shown in Table 22a for first year (2014-15) and Table 22b for second year (2015-16) respectively. Significantly higher LWR was observed in BARI Gom 24 (V_1) than BARI Gom 26 (V_2) within the period of 35-50 and 50-65 DAS in both the years.

The effects of split applications of nitrogen on leaf weight ratio (LWR) at different growth stages are presented in Table 23a and Fig. 22a for first year (2014-15) and Table 23b and Fig. 22b for second year (2015-16) respectively. The LWR showed a downward trend with plant age in all the treatments in both the years. LWR did not differ significantly within the period 20-35 and 35-50 DAS while LWR varied significantly within the period 50-65 and 65-80 DAS due to split applications of nitrogen in both the years. During 50-65 and 65-80 DAS, the highest LWR was found in control (N_0) and the lowest LWR was observed in basal (N_1) in both the growing seasons. The decrease of LWR was caused by decreased plant dry weight

and decreased LAI at the later stages. Saha and Paul (1995) observed sharp increase of total dry matter resulted in sharp decrease in LWR. Sharp decrease of LWR at the later stages in wheat was also noticed by Sarker and Paul (1998) and Nahar and Paul (1998). Alam (2014) stated that nitrogen level showed significant effect on LWR. The highest LWR was recorded from 160 kg N ha⁻¹ and the lowest in control.

LWR was significantly influenced by the interaction of irrigation and nitrogen during 50-65 and 65-80 DAS in both the years while LWR did not differ significantly within the periods of 20-35 and 35-50 DAS in both the years and are shown in Table 24a for first year (2014-15) and Table 24b for second year (2015-16) respectively. During 50-65 DAS, the highest LWR was observed in treatment combination of $I_1 \times N_0$ followed by $I_0 \times N_0$, $I_2 \times N_0$ and $I_3 \times N_0$ and the lowest LWR was found in $I_0 \times N_1$ in both the years. Within the period of 65-80 DAS, the highest LWR was achieved in $I_1 \times N_0$ followed by $I_2 \times N_0$ and the lowest LWR was observed in $I_0 \times N_2$ in both the years.

Table 21 a: Effect of irrigation on leaf weight ratio of wheat (2014-15)

Irrigation	Leaf weight ratio (g g ⁻¹)			
	20-35 DAS	35-50 DAS	50-65 DAS	65-80 DAS
I ₀	0.537 b	0.460 b	0.355 b	0.319 b
I ₁	0.544 ab	0.470 ab	0.370 a	0.336 ab
I ₂	0.553 a	0.469 a	0.368 a	0.339 a
I ₃	0.553 a	0.470 a	0.365 a	0.334 ab
CV (%)	12.89	13.353	6.316	6.377

At specific days after sowing, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

Table 21 b: Effect of irrigation on leaf weight ratio of wheat (2015-16)

Irrigation	Leaf weight ratio (g g ⁻¹)			
	20-35 DAS	35-50 DAS	50-65 DAS	65-80 DAS
I ₀	0.536 b	0.457 b	0.351 b	0.320 b
I ₁	0.546 a	0.471 a	0.368 a	0.337 ab
I ₂	0.546 a	0.470 a	0.370 a	0.340 a
I ₃	0.546 a	0.471 a	0.369 a	0.335 ab
CV (%)	12.941	13.359	6.340	6.378

At specific days after sowing, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

Table 22 a: Effect of variety on leaf weight ratio of wheat (2014-15)

Variety	Leaf weight ratio (g g ⁻¹)			
	20-35 DAS	35-50 DAS	50-65 DAS	65-80 DAS
V ₁	0.545 a	0.471 a	0.371 a	0.335 a
V ₂	0.548 a	0.463 b	0.358 b	0.330 a
CV (%)	12.89	13.353	6.316	6.377

At specific days after sowing, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

Table 22 b: Effect of variety on leaf weight ratio of wheat (2015-16)

Variety	Leaf weight ratio (g g ⁻¹)			
	20-35 DAS	35-50 DAS	50-65 DAS	65-80 DAS
V ₁	0.542 a	0.472 a	0.371 a	0.336 a
V ₂	0.545 a	0.463 b	0.358 b	0.330 a
CV (%)	12.941	13.359	6.340	6.378

At specific days after sowing, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

Table 23 a: Effect of nitrogen on leaf weight ratio of wheat (2014-15)

Nitrogen	Leaf weight ratio (g g ⁻¹)			
	20-35 DAS	35-50 DAS	50-65 DAS	65-80 DAS
N ₀	0.547 a	0.469 a	0.396 a	0.376 a
N ₁	0.547 a	0.466 a	0.352 b	0.317 b
N ₂	0.549 a	0.467 a	0.355 b	0.318 b
N ₃	0.544 a	0.465 a	0.354 b	0.318 b
CV (%)	12.89	13.353	6.316	6.377

At specific days after sowing, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

Table 23 b: Effect of nitrogen on leaf weight ratio of wheat (2015-16)

Nitrogen	Leaf weight ratio (g g ⁻¹)			
	20-35 DAS	35-50 DAS	50-65 DAS	65-80 DAS
N ₀	0.544 a	0.470 a	0.396 a	0.377 a
N ₁	0.544 a	0.467 a	0.352 b	0.318 b
N ₂	0.546 a	0.467 a	0.356 b	0.319 b
N ₃	0.541 a	0.466 a	0.354 b	0.319 b
CV (%)	12.941	13.359	6.340	6.378

At specific days after sowing, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

Table 24 a: Interaction effect of irrigation and nitrogen on leaf weight ratio of wheat (2014-15)

Interaction (Irrigation × Nitrogen)	Leaf weight ratio (g g ⁻¹)			
	20-35 DAS	35-50 DAS	50-65 DAS	65-80 DAS
I ₀ N ₀	.0546 a	0.471 a	0.391 a	0.364 b
I ₀ N ₁	0.535 a	0.455 a	0.340 c	0.305 d
I ₀ N ₂	0.535 a	0.456 a	0.344 bc	0.303 d
I ₀ N ₃	0.533 a	0.457 a	0.343 bc	0.304 d
I ₁ N ₀	0.542 a	0.468 a	0.402 a	0.391 a
I ₁ N ₁	0.545 a	0.472 a	0.359 bc	.0317 c
I ₁ N ₂	0.548 a	0.472 a	0.358 bc	0.320 c
I ₁ N ₃	0.541 a	0.469 a	0.360 bc	0.317 c
I ₂ N ₀	0.549 a	0.465 a	0.396 a	0.383 a
I ₂ N ₁	0.554 a	0.471 a	0.356 bc	0.325 c
I ₂ N ₂	0.557 a	0.470 a	0.361 b	0.324 c
I ₂ N ₃	0.552 a	0.469 a	0.358 bc	0.325 c
I ₃ N ₀	0.551 a	0.473 a	0.393 a	0.367 b
I ₃ N ₁	0.556 a	0.468 a	0.353 bc	0.323 c
I ₃ N ₂	0.555 a	0.470 a	0.360 bc	0.324 c
I ₃ N ₃	0.551 a	0.468 a	0.356 bc	0.323 c
CV (%)	12.89	13.353	6.316	6.377

At specific days after sowing, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

Table 24 b: Interaction effect of irrigation and nitrogen on leaf weight ratio of wheat (2015-16)

Interaction (Irrigation × Nitrogen)	Leaf weight ratio (g g ⁻¹)			
	20-35 DAS	35-50 DAS	50-65 DAS	65-80 DAS
I ₀ N ₀	0.545 a	0.469 a	0.387 a	0.365 b
I ₀ N ₁	0.534 a	0.453 a	0.337 d	0.306 d
I ₀ N ₂	0.533 a	0.453 a	0.340 cd	0.304 d
I ₀ N ₃	0.532 a	0.454 a	0.339 cd	0.305 d
I ₁ N ₀	0.544 a	0.469 a	0.400 a	0.392 a
I ₁ N ₁	0.547 a	0.473 a	0.357 bc	0.318 c
I ₁ N ₂	0.551 a	0.473 a	0.356 b-d	0.320 c
I ₁ N ₃	0.543 a	0.470 a	0.357 bc	0.318 c
I ₂ N ₀	0.541 a	0.466 a	0.398 a	0.384 a
I ₂ N ₁	0.547 a	0.472 a	0.358 bc	0.326 c
I ₂ N ₂	0.550 a	0.471 a	0.363 b	0.325 c
I ₂ N ₃	0.545 a	0.470 a	0.361 b	0.326 c
I ₃ N ₀	0.543 a	0.474 a	0.397 a	0.368 b
I ₃ N ₁	0.548 a	0.469 a	0.356 b-d	0.323 c
I ₃ N ₂	0.548 a	0.470 a	0.364 b	0.325 c
I ₃ N ₃	0.544 a	0.469 a	0.360 b	0.324 c
CV (%)	12.941	13.359	6.340	6.378

At specific days after sowing, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

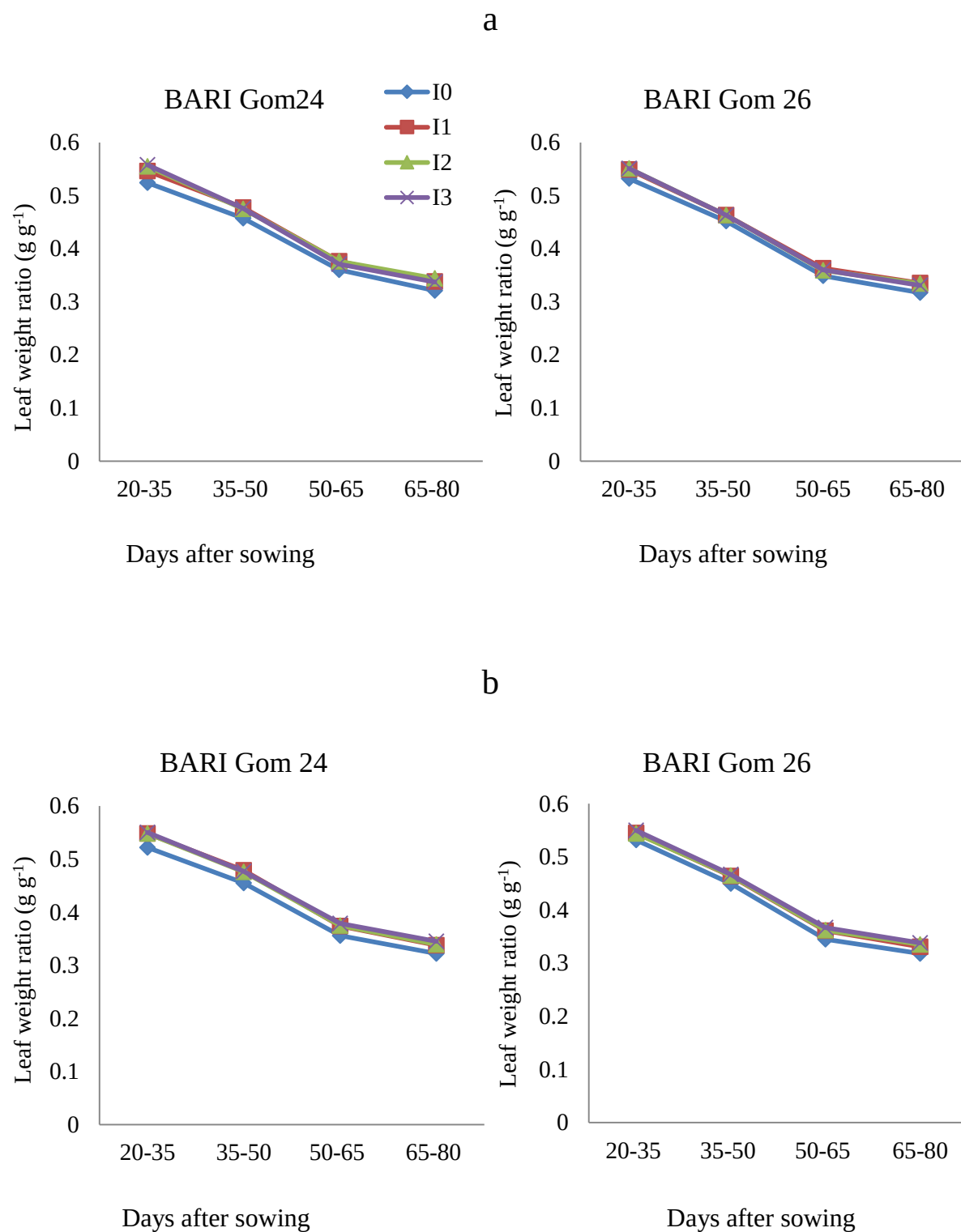


Fig. 21 Effect of irrigation on leaf weight ratio at different days after sowing in 2014-15(a) and 2015-16(b)

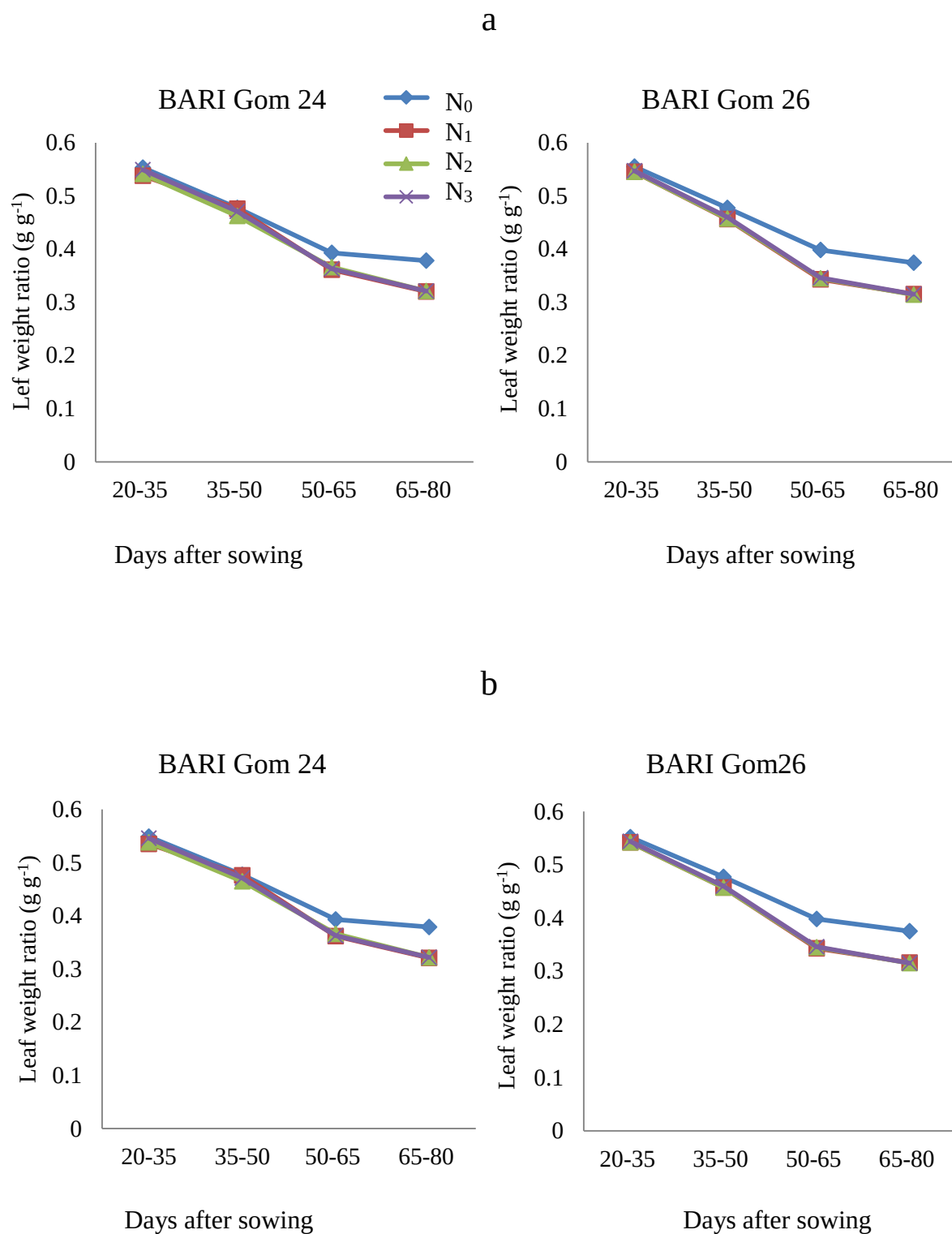


Fig. 22 Effect of nitrogen on leaf weight ratio at different days after sowing in 2014-15(a) and 2015-16(b)

4.2. Phenological stages

Number of days required for attaining different phenological stages varied significantly due to irrigation levels in both the years and are presented in Table 25a for first year (2014-15) and Table 25b for second year (2015-16) respectively. Days required for crown root initiation were non-significant due to irrigation levels in both the years. Days required for crown root initiation for all treatments were almost similar as no supplemental irrigation was applied before that stage to any treatment. Days to tillering was less affected by irrigation in both the years because one irrigation was applied before that stage. But days required for booting, heading, anthesis and physiological maturity showed significant differences due to variation of irrigation levels. The time taken for booting, heading, anthesis and physiological maturity increased with increasing irrigation frequencies. The plants grown in three (I_3) irrigation conditions needed higher days for booting, heading, anthesis and physiological maturity followed by two (I_2) and one (I_1) irrigation and I_0 plant required the lowest days for attaining these stages in both the growing seasons. It might be due to the sufficient availability of water at those stages with more uptakes of nutrients. The non-irrigated control plants required minimum days for attaining different phenological stages in both the years. Similar results were also reported by Pal *et al.* (1996). Day and Intalap (1970) opined that maturity of wheat plants was hastened due to the stress at flowering and dough stages. Gales and Wilson (1979) observed that the stressed plants matured earlier than the irrigated plants. Mostafavi and Niknejad (1983), Gales and Wilson (1979) noticed that the plants suffering water shortage matured earlier than the well-watered wheat plants. Haider (2002) and Ngwako and Mashiq (2013) also reported similar result with wheat varieties. Bahadur (2008) also found similar results in barley.

Variety had no significant effect on phenological stages in both the years and is shown in Table 26a for first year (2014-15) and Table 26b for second year (2015-16) respectively. Between the two varieties, BARI Gom 26 required maximum days for attaining their different phenological stage in both the years.

Split applications of nitrogen had significant effect on phenological stages in both the years and are presented in Table 27a for first year (2014-15) and Table 27b for second year (2015-16) respectively. The more days to crown root initiation and tillering were observed in basal (N_1) application of nitrogen followed by three (N_2) and Four (N_3) split applications of nitrogen and the least days to crown root initiation and tillering were found in control (N_0) in both the years. At crown root initiation and tillering stages, amount and availability of

nitrogen was high in basal (N_1) dose. But later stages, nitrogen availability decreased rapidly because nitrogen was not applied at those periods. The more days to booting and heading were recorded in three (N_2) split applications of nitrogen followed by four (N_3) split applications of nitrogen because in these stages amount and availability of nitrogen was high. But four (N_3) split application of nitrogen showed the longest time and control (N_0) showed shortest time to anthesis and physiological maturity. At booting and heading stages, amount and availability of nitrogen was high in three (N_2) split applications while four (N_3) split applications of nitrogen ensure more availability of nitrogen at anthesis and physiological maturity stages in both the years. Similar results were reported by Sardana and Zhang (2005), Amanullah *et al.* (2013), Sharifi and Namvar (2016) and Sharifi *et al.* (2016) in maize. It is understandable, because nitrogen is a structural element of chlorophyll and protein molecules, and thereby affects formation of chloroplasts and accumulation of chlorophyll in them (Tucker 2004). Chlorophyll content is approximately proportional to leaf nitrogen content, too (Bojovic and Markovic, 2009).

The combined effects of irrigation levels and split applications on phenology are presented in Table 28a for first year (2014-15) and Table 28b for second year (2015-16). The interaction effect between time of irrigation and split applications of nitrogen were significant for the phenology of wheat. The longest time to crown root initiation was observed in the combinations of $I_0 \times N_1$, $I_1 \times N_1$ and $I_2 \times N_1$ followed by $I_3 \times N_1$ and the shortest time was required in $I_3 \times N_0$ followed by $I_1 \times N_0$ in both the years. The maximum days required for tillering in $I_1 \times N_1$, $I_2 \times N_1$ and $I_3 \times N_1$ followed by $I_0 \times N_1$ and the minimum days required for tillering in $I_0 \times N_0$ followed by $I_1 \times N_0$ and $I_3 \times N_0$ in both the years. The longest time to booting, heading and anthesis were recorded in the combinations of $I_3 \times N_2$ followed by $I_3 \times N_3$ and $I_2 \times N_2$ and the shortest time was found in $I_0 \times N_0$ in both the years. The maximum days required for physiological maturity was observed in $I_3 \times N_3$ which was statistically identical with $I_3 \times N_2$ and the minimum days required in $I_0 \times N_0$ in both the years.

Table 25a: Effect of irrigation on the phenological stages of wheat (2014-2015)

Irrigation	Crown root initiation stage	Tillering stage	Booting stage	Heading stage	Anthesis stage	Physiological maturity stage
I ₀	18.750 a	22.125 b	52.208 d	58.125 c	62.917 c	92.208 d
I ₁	18.958 a	23.208 a	54.500 c	60.542 b	65.250 bc	95.167 c
I ₂	18.958 a	23.542 a	56.208 b	62.500 ab	67.250 ab	98.917 b
I ₃	19.083 a	23.458 a	57.875 a	63.917 a	68.583 a	102.083 a
CV (%)	14.94	11.63	4.38	4.75	3.23	2.76

At specific days after sowing, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

Table 25b: Effect of irrigation on the phenological stages of wheat (2015-2016)

Irrigation	Crown root initiation stage	Tillering stage	Booting stage	Heading stage	Anthesis stage	Physiological maturity stage
I ₀	19.125 a	22.789 b	54.036 d	60.218 c	65.056 c	93.591 d
I ₁	19.338 a	23.905 a	56.408 c	62.721 b	67.469 bc	96.594 c
I ₂	19.338 a	24.248 a	58.176 b	64.750 ab	69.537 ab	100.400 b
I ₃	19.465 a	24.162 a	59.901 a	66.218 a	70.915 a	103.615 a
CV (%)	14.94	11.63	4.38	4.75	3.23	2.76

At specific days after sowing, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

Table 26a: Effect of variety on the phenological stages of wheat (2014-2015)

Variety	Crown root initiation stage	Tillering stage	Booting stage	Heading stage	Anthesis stage	Physiological maturity stage
V ₁	18.688 a	22.854 a	54.958 a	61.083 a	65.313 a	96.792 a
V ₂	19.188 a	23.312 a	55.438 a	61.458 a	66.688 a	97.396 a
CV (%)	14.94	11.63	4.38	4.75	3.23	2.76

At specific days after sowing, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

Table 26b: Effect of variety on the phenological stages of wheat (2015-2016)

Variety	Crown root initiation stage	Tillering stage	Booting stage	Heading stage	Anthesis stage	Physiological maturity stage
V ₁	19.061 a	23.540 a	56.882 a	63.282 a	67.533a	98.244 a
V ₂	19.571 a	24.012 a	57.378 a	63.671 a	68.955 a	98.857 a
CV (%)	14.94	11.63	4.38	4.75	3.23	2.76

At specific days after sowing, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

Table 27a: Effect of nitrogen on the phenological stages of wheat (2014-2015)

Nitrogen	Crown root initiation stage	Tillering stage	Booting stage	Heading stage	Anthesis stage	Physiological maturity stage
N ₀	17.583 d	21.500 c	52.500 c	56.958 c	61.458 c	92.333 c
N ₁	20.708 a	24.458 a	55.167 b	60.917 b	65.208 b	95.875 b
N ₂	19.167 b	23.500 b	57.083 a	64.708 a	69.208 a	99.417 a
N ₃	18.292 c	22.875 b	56.042 ab	62.500 b	68.125 a	100.750 a
CV (%)	14.94	11.63	4.38	4.75	3.23	2.76

At specific days after sowing, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

Table 27b: Effect of nitrogen on the phenological stages of wheat (2015-2016)

Nitrogen	Crown root initiation stage	Tillering stage	Booting stage	Heading stage	Anthesis stage	Physiological maturity stage
N ₀	17.935 d	22.145 c	54.338 c	59.009 c	63.548 c	93.718 c
N ₁	21.123 a	25.192 a	57.098 b	63.110 b	67.425 b	97.313 b
N ₂	19.550 b	24.205 b	59.081 a	67.038 a	71.561 a	100.908 a
N ₃	18.658 c	23.561 b	58.003 ab	64.750 b	70.441 a	102.261 a
CV (%)	14.94	11.63	4.38	4.75	3.23	2.76

At specific days after sowing, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

Table 28a: Interaction effect of irrigation and nitrogen on the phenological stages of wheat (2014-2015)

Interaction (Irrigation × Nitrogen)	Crown root initiation stage	Tillering stage	Booting stage	Heading stage	Anthesis stage	Physiological maturity stage
I ₀ N ₀	17.833 c-e	20.833 f	49.500 j	53.833 i	58.333 i	88.333 h
I ₀ N ₁	20.833 a	23.333 a-d	52.333 i	58.000 g	62.500 gh	90.500 g
I ₀ N ₂	19.333 a-c	22.500 c-e	53.833 gh	61.333 de	65.833 d-f	94.167 f
I ₀ N ₃	18.333 c-e	21.833 d-f	53.167 hi	59.333 fg	65.000 ef	95.833 e
I ₁ N ₀	17.667 de	21.667 ef	51.833 i	56.333 h	60.833 h	90.833 g
I ₁ N ₁	20.833 a	24.833 a	54.500 f-h	60.167 ef	64.500 e-g	94.000 f
I ₁ N ₂	19.000 b-d	23.500 a-c	56.333 de	63.833 c	68.333 c	97.000 de
I ₁ N ₃	18.333 c-e	22.833 b-e	55.333 ef	61.833 d	67.333 cd	98.833 c
I ₂ N ₀	17.833 c-e	21.833 d-f	53.833 gh	58.333 g	62.833 gh	93.833 f
I ₂ N ₁	20.833 a	24.833 a	55.833 d-f	61.833 d	66.000 de	97.667 cd
I ₂ N ₂	19.000 b-d	24.167 ab	58.333 b	66.333 ab	70.833 ab	101.333 b
I ₂ N ₃	18.167 c-e	23.333 a-d	56.833 cd	63.500 c	69.333 bc	102.833 b
I ₃ N ₀	17.000 e	21.667 ef	54.833 fg	59.333 fg	63.833 fg	96.333 de
I ₃ N ₁	20.333 ab	24.833 a	58.000 bc	63.667 c	67.833 cd	101.333 b
I ₃ N ₂	19.333 a-c	23.833 a-c	59.833 a	67.333 a	71.833 a	105.167 a
I ₃ N ₃	18.333 c-e	23.500 a-c	58.833 ab	65.333 b	70.833 ab	105.500 a
CV (%)	14.94	11.63	4.38	4.75	3.23	2.76

At specific days after sowing, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

Table 28b: Interaction effect of irrigation and nitrogen on the phenological stages of wheat (2015-2016)

Interaction (Irrigation × Nitrogen)	Crown root initiation stage	Tillering stage	Booting stage	Heading stage	Anthesis stage	Physiological maturity stage
I ₀ N ₀	18.190 c-e	21.458 f	51.233 j	55.771 i	60.317 i	89.658 h
I ₀ N ₁	21.250 a	24.033 a-d	54.165 i	60.088 g	64.625 gh	91.858 g
I ₀ N ₂	19.720 a-c	23.175 c-e	55.718 gh	63.541 de	68.072 d-f	95.579 f
I ₀ N ₃	18.700 c-e	22.488 d-f	55.028 hi	61.469 fg	67.210 ef	97.271 e
I ₁ N ₀	18.020 de	22.317 ef	53.648 i	58.361 h	62.902 h	92.196 g
I ₁ N ₁	21.250 a	25.578 a	56.408 f-h	62.333 ef	66.693 e-g	95.410 f
I ₁ N ₂	19.380 b-d	24.205 a-c	58.305 de	66.131 c	70.657 c	98.455 de
I ₁ N ₃	18.700 c-e	23.518 b-e	57.270 ef	64.059 d	69.623 cd	100.316 c
I ₂ N ₀	18.190 c-e	22.488 d-f	55.718 gh	60.433 g	64.970 gh	95.241 f
I ₂ N ₁	21.250 a	25.578 a	57.788 d-f	64.059 d	68.244 de	99.132 cd
I ₂ N ₂	19.380 b-d	24.892 ab	60.375 b	68.721 ab	73.242 ab	102.853 b
I ₂ N ₃	18.530 c-e	24.033 a-d	58.823 cd	65.786 c	71.691 bc	104.376 b
I ₃ N ₀	17.340 e	22.317 ef	56.753 fg	61.469 fg	66.004 fg	97.778 de
I ₃ N ₁	20.740 ab	25.578 a	60.030 bc	65.959 c	70.140 cd	102.853 b
I ₃ N ₂	19.720 a-c	24.548 a-c	61.928 a	69.757 a	74.276 a	106.744 a
I ₃ N ₃	18.700 c-e	24.205 a-c	60.893 ab	67.685 b	73.242 ab	107.083 a
CV (%)	14.94	11.63	4.38	4.75	3.23	2.76

At specific days after sowing, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

4.3. Plant height, dry matter distribution and leaf area at different phenological stages

4.3.1. Crown root initiation stage (CRI stage)

The effect of irrigation on plant height, leaf dry weight, stem dry weight, total dry weight plant⁻¹ and leaf area plant⁻¹ at the crown root initiation stage are presented in Table 29a for first year (2014-15) and in Table 29b for second year (2015-16). Irrigation treatments had significant effect on leaf dry weight plant⁻¹, stem dry weight plant⁻¹ and total dry weight plant⁻¹ at crown root initiation (CRI) stage in both the years. Irrigated plants were produced statistically identical leaf dry weight plant⁻¹, stem dry weight plant⁻¹ and total dry weight plant⁻¹ and rain-fed (I₀) condition gave the lowest leaf dry weight plant⁻¹, stem dry weight plant⁻¹ and total dry weight plant⁻¹ in both the years. Plant height, leaf dry weight, stem dry weight, total dry weight plant⁻¹ and leaf area plant⁻¹ were almost similar up to the crown root initiation stage, as no supplemental irrigation was applied before that stage to any treatment. Generally, leaves accumulated higher dry matter than stem in both the irrigated and non-irrigated crops at the CRI stage. However, a marked decline was observed when irrigation was imposed at 20 DAS to treatment I₀.

Leaf dry weight plant⁻¹, stem dry weight plant⁻¹ and total dry weight plant⁻¹ varied significantly due to varieties at crown root initiation (CRI) stage in both the years and plant height and leaf area plant⁻¹ did not differ significantly due to varieties at crown root initiation (CRI) stage in both the years are shown in Table 30a for first year (2014-15) and Table 30b for second year (2015-16). Significantly higher leaf dry weight plant⁻¹, stem dry weight plant⁻¹ and total dry weight plant⁻¹ were observed in BARI Gom 24 (V₁) at crown root initiation (CRI) stage in both the years.

Plant height, leaf dry weight plant⁻¹, stem dry weight plant⁻¹, total dry weight plant⁻¹ and leaf area plant⁻¹ at crown root initiation (CRI) stage were significantly influenced due to split applications of nitrogen in both the years and are presented in Table 31a for first year (2014-15) and in Table 31b for second year (2015-16). All nitrogen treatments except control (N₀) produced more or less similar plant height, leaf dry weight plant⁻¹, stem dry weight plant⁻¹, total dry weight plant⁻¹ and leaf area plant⁻¹ in both the years. Khursheed and Mahammad (2015) reported that N fertilizer significantly increased plant height, shoot dry weight and leaf area.

Table 29a: Effect of irrigation on plant height, dry weights and leaf area of wheat at crown root initiation stage (2014-15)

Irrigation	Plant height(cm)	Leaf dry weight plant ⁻¹ (g)	Stem dry weight plant ⁻¹ (g)	Total dry weight plant ⁻¹ (g)	Leaf area plant ⁻¹ (cm ²)
I ₀	20.380 a	0.142 b	0.120 b	0.262 b	10.105 a
I ₁	20.281 a	0.168 a	0.134 a	0.303 a	10.159 a
I ₂	20.244 a	0.167 a	0.135 a	0.303 a	10.145 a
I ₃	20.435 a	0.169 a	0.137 a	0.307 a	10.181 a
CV (%)	14.251	12.758	11.609	6.790	2.046

At specific days after sowing, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

Table 29b: Effect of irrigation on plant height, dry weights and leaf area of wheat at crown root initiation stage (2015-16)

Irrigation	Plant height(cm)	Leaf dry weight plant ⁻¹ (g)	Stem dry weight plant ⁻¹ (g)	Total dry weight plant ⁻¹ (g)	Leaf area plant ⁻¹ (cm ²)
I ₀	20.769 a	0.144 b	0.122 b	0.266 b	10.289 a
I ₁	20.639 a	0.171 a	0.138 a	0.309 a	10.328 a
I ₂	20.605 a	0.170 a	0.138 a	0.308 a	10.324 a
I ₃	20.785 a	0.172 a	0.140 a	0.312 a	10.352 a
CV (%)	14.273	12.736	11.647	6.791	2.046

At specific days after sowing, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

Table 30a: Effect of variety on plant height, dry weights and leaf area of wheat at crown root initiation stage (2014-15)

Variety	Plant height(cm)	Leaf dry weight plant ⁻¹ (g)	Stem dry weight plant ⁻¹ (g)	Total dry weight plant ⁻¹ (g)	Leaf area plant ⁻¹ (cm ²)
V ₁	20.409 a	0.175 a	0.143 a	0.317 a	10.141 a
V ₂	20.261 a	0.149 b	0.123 b	0.270 b	10.154 a
CV (%)	14.251	12.758	11.609	6.790	2.046

At specific days after sowing, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

Table 30b: Effect of variety on plant height, dry weights and leaf area of wheat at crown root initiation stage (2015-16)

Variety	Plant height(cm)	Leaf dry weight plant ⁻¹ (g)	Stem dry weight plant ⁻¹ (g)	Total dry weight plant ⁻¹ (g)	Leaf area plant ⁻¹ (cm ²)
V ₁	20.775 a	0.178 a	0.145 a	0.323 a	10.317 a
V ₂	20.624 a	0.151 b	0.124 b	0.275 b	10.330 a
CV (%)	14.273	12.736	11.647	6.791	2.046

At specific days after sowing, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

Table 31a: Effect of nitrogen on plant height, dry weights and leaf area of wheat at crown root initiation stage (2014-15)

Nitrogen	Plant height(cm)	Leaf dry weight plant ⁻¹ (g)	Stem dry weight plant ⁻¹ (g)	Total dry weight plant ⁻¹ (g)	Leaf area plant ⁻¹ (cm ²)
N ₀	19.026 d	0.131 b	0.106 b	0.237 b	8.669 c
N ₁	21.589 a	0.177 a	0.144 a	0.321 a	11.092 a
N ₂	20.616 b	0.174 a	0.141 a	0.314 a	10.499 b
N ₃	20.109 c	0.165 a	0.137 a	0.302 a	10.331 c
CV (%)	14.251	12.758	11.609	6.790	2.046

At specific days after sowing, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

Table 31b: Effect of nitrogen on plant height, dry weights and leaf area of wheat at crown root initiation stage (2015-16)

Nitrogen	Plant height(cm)	Leaf dry weight plant ⁻¹ (g)	Stem dry weight plant ⁻¹ (g)	Total dry weight plant ⁻¹ (g)	Leaf area plant ⁻¹ (cm ²)
N ₀	19.367 d	0.133b	0.108 b	0.241 b	8.819 d
N ₁	21.976 a	0.180 a	0.147 a	0.327 a	11.284 a
N ₂	20.986 b	0.176 a	0.143 a	0.319 a	10.681 b
N ₃	20.469 c	0.168 a	0.140 a	0.308 a	10.510 c
CV (%)	14.273	12.736	11.647	6.791	2.046

At specific days after sowing, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

Table 32a: Interaction effect of irrigation and nitrogen on plant height, dry weights and leaf area of wheat at crown root initiation stage (2014-15)

Interaction (Irrigation × Nitrogen)	Plant height(cm)	Leaf dry weight plant ⁻¹ (g)	Stem dry weight plant ⁻¹ (g)	Total dry weight plant ⁻¹ (g)	Leaf area plant ⁻¹ (cm ²)
I ₀ N ₀	19.175 d	0.126 d	0.102 d	0.228 e	8.636 e
I ₀ N ₁	21.522 ab	0.151 b-d	0.129 a-c	0.280 b-e	11.059 a
I ₀ N ₂	20.659 c	0.148 cd	0.127 a-c	0.275 c-e	10.439 bc
I ₀ N ₃	20.163 c	0.142 cd	0.123 b-d	0.265 de	10.286 d
I ₁ N ₀	18.916 d	0.132 d	0.106 cd	0.238 e	8.693 e
I ₁ N ₁	21.516 ab	0.186 a	0.150 a	0.335 a	11.098 a
I ₁ N ₂	20.618 c	0.182 ab	0.145 ab	0.327 a-c	10.508 b
I ₁ N ₃	20.072 c	0.171 a-c	0.142 ab	0.313 a-d	10.336 cd
I ₂ N ₀	18.978 d	0.132 d	0.107 cd	0.239 e	8.651 e
I ₂ N ₁	21.579 a	0.184 a	0.149 a	0.333 ab	11.091 a
I ₂ N ₂	20.425 c	0.181 ab	0.144 ab	0.325 a-c	10.505 b
I ₂ N ₃	19.994 c	0.173 a-c	0.142 ab	0.314 a-d	10.335 cd
I ₃ N ₀	19.034 d	0.136 d	0.110 cd	0.245 e	8.694 e
I ₃ N ₁	21.737 a	0.187 a	0.150 a	0.336 a	11.118 a
I ₃ N ₂	20.763 bc	0.183 a	0.147 a	0.331 ab	10.546 b
I ₃ N ₃	20.205 c	0.173 a-c	0.143 ab	0.316 a-d	10.366 cd
CV (%)	14.251	12.758	11.609	6.790	2.046

At specific days after sowing, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

Table 32b: Interaction effect of irrigation and nitrogen on plant height, dry weights and leaf area of wheat at crown root initiation stage (2015-16)

Interaction (Irrigation × Nitrogen)	Plant height(cm)	Leaf dry weight plant ⁻¹ (g)	Stem dry weight plant ⁻¹ (g)	Total dry weight plant ⁻¹ (g)	Leaf area plant ⁻¹ (cm ²)
I ₀ N ₀	19.542 d	0.128 d	0.104 d	0.232 e	8.793 e
I ₀ N ₁	21.933 a	0.153 b-d	0.131 a-c	0.284 b-e	11.260 a
I ₀ N ₂	21.054 c	0.150 cd	0.129 a-c	0.279 c-e	10.628 bc
I ₀ N ₃	20.549 c	0.144 cd	0.125 b-d	0.269 de	10.473 d
I ₁ N ₀	19.251 d	0.134 d	0.108 cd	0.242 e	8.838 e
I ₁ N ₁	21.896 ab	0.189 a	0.153 a	0.342 a	11.283 a
I ₁ N ₂	20.983 c	0.185 ab	0.147 ab	0.332 a-c	10.683 b
I ₁ N ₃	20.426 c	0.174 a-c	0.144 ab	0.318 a-d	10.508 d
I ₂ N ₀	19.317 d	0.134 d	0.109 cd	0.243 e	8.803 e
I ₂ N ₁	21.964 a	0.187 a	0.152 a	0.339 ab	11.287 a
I ₂ N ₂	20.789 c	0.184 ab	0.147 ab	0.331 a-c	10.690 b
I ₂ N ₃	20.351 c	0.176 a-c	0.144 ab	0.320 a-d	10.517 d
I ₃ N ₀	19.361 d	0.137d	0.112 cd	0.249 e	8.840 e
I ₃ N ₁	22.110 a	0.190 a	0.153 a	0.343 a	11.305 a
I ₃ N ₂	21.119 bc	0.186 a	0.150 a	0.336 ab	10.723 b
I ₃ N ₃	20.551 c	0.176 a-c	0.145 ab	0.321 a-d	10.540 cd
CV (%)	14.273	12.736	11.647	6.791	2.046

At specific days after sowing, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

Different treatment combinations of irrigation and nitrogen had significant effect on plant height, leaf dry weight plant⁻¹, stem dry weight plant⁻¹, total dry weight plant⁻¹ and leaf area plant⁻¹ at crown root initiation (CRI) stage in both the years are shown in Table 32a for first year (2014-15) and Table 32b for second year (2015-16). With a few exceptions, the highest plant height, leaf dry weight plant⁻¹, stem dry weight plant⁻¹, total dry weight plant⁻¹ and leaf area plant⁻¹ was observed in irrigated plant with basal application of nitrogen ($I_1 \times N_1$, $I_2 \times N_1$ and $I_3 \times N_1$) and the lowest value was obtained in rain-fed (I_0) $\times$ control (N_0) at crown root initiation (CRI) stage in both the years.

4.3.2. Tillering stage

Irrigation treatments had significant effect on plant height, leaf dry weight plant⁻¹, stem dry weight plant⁻¹ and total dry weight plant⁻¹ and irrigation levels had no significant effect on leaf area plant⁻¹ at tillering stage in both the years and are presented in Table 33a for first year (2014-15) and in Table 33b for second year (2015-16). Irrigated plants were produced statistically more or less similar plant height, leaf dry weight plant⁻¹, stem dry weight plant⁻¹ and total dry weight plant⁻¹ and the lowest values were recorded in rain-fed (I_0) condition at tillering stage in both the years. The increase in plant height, leaf dry weight plant⁻¹, stem dry weight plant⁻¹ and total dry weight plant⁻¹ of two varieties might be due to the sufficient availability of water at tillering stage with more uptakes of nutrients. Mollah and Paul (2011) stated that plant height increased with the increase of irrigation in barley. Similar result was reported in wheat (Pandit *et al.*, 2001 and Naeem Sarwar 2010). Abdorrahmani *et al.* (2005) reported that two irrigations produced highest TDM and moisture stress reduced TDM production. Ashok and Sharma (2004) observed that the irrigation treatments increased TDM. Similar result was reported in wheat (Nahar and Paul 1998, Rahman *et al.*, 2001 and Shen *et al.*, 2001).

Leaf dry weight plant⁻¹, stem dry weight plant⁻¹ and total dry weight plant⁻¹ varied significantly due to varieties at tillering stage in both the years and are shown in Table 34a for first year (2014-15) and Table 34b for second year (2015-16). Significantly higher leaf dry weight plant⁻¹, stem dry weight plant⁻¹ and total dry weight plant⁻¹ were observed in BARI Gom 24 (V_1) at tillering stage in both the years.

Split applications of nitrogen had significant effect on plant height, leaf dry weight plant⁻¹, stem dry weight plant⁻¹, total dry weight plant⁻¹ and leaf area plant⁻¹ at tillering stage in both the years and are presented in Table 35a for first year (2014-15) and in Table 35b for second

year (2015-16). With a few exceptions, all nitrogen treatments except control (N_0) produced more or less similar plant height, leaf dry weight plant^{-1} , stem dry weight plant^{-1} , total dry weight plant^{-1} and leaf area plant^{-1} . Khursheed and Mahammad (2015) reported that N fertilizer significantly increased plant height, shoot dry weight and leaf area. Chaturvedi (2006) reported that plant height and TDM increased with increasing nitrogen availability at all critical stages. Ananda (2004) reported that split application of nitrogen as three split recorded maximum plant height of wheat. Wagan *et al.* (2002) reported that nitrogen applied in three split doses significantly increased plant height. Shehzad *et al.* (2012) reported that all treatments significantly enhanced the plant height over the control.

Plant height, leaf dry weight plant^{-1} , stem dry weight plant^{-1} , total dry weight plant^{-1} and leaf area plant^{-1} in both the years varied significantly due to interaction of irrigation and nitrogen at tillering stage and are shown in Table 36a for first year (2014-15) and in Table 36b for second year (2015-16). With a few exceptions, irrigated plants with basal application of nitrogen were produced the highest plant height, leaf dry weight plant^{-1} , stem dry weight plant^{-1} , total dry weight plant^{-1} and leaf area plant^{-1} in both the years. The lowest values of plant height, leaf dry weight plant^{-1} , stem dry weight plant^{-1} , total dry weight plant^{-1} and leaf area plant^{-1} in both the years were obtained in rain-fed (I_0) $\times$ control (N_0).

Table 33a: Effect of irrigation on plant height, dry weights and leaf area of wheat at tillering stage (2014-15)

Irrigation	Plant height(cm)	Leaf dry weight plant ⁻¹ (g)	Stem dry weight plant ⁻¹ (g)	Total dry weight plant ⁻¹ (g)	Leaf area plant ⁻¹ (cm ²)
I ₀	33.549 b	0.544 b	0.483 b	1.027 b	77.411 a
I ₁	38.428 a	0.664 a	0.562 a	1.225 a	83.215 a
I ₂	38.464 a	0.684 a	0.579 a	1.263 a	83.328 a
I ₃	38.529 a	0.724 a	0.612 a	1.337 a	83.409 a
CV (%)	5.673	13.206	3.682	12.484	2.062

At specific days after sowing, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

Table 33b: Effect of irrigation on plant height, dry weights and leaf area of wheat at tillering stage (2015-16)

Irrigation	Plant height(cm)	Leaf dry weight plant ⁻¹ (g)	Stem dry weight plant ⁻¹ (g)	Total dry weight plant ⁻¹ (g)	Leaf area plant ⁻¹ (cm ²)
I ₀	34.195 b	0.554 b	0.493 b	1.047 b	78.891 a
I ₁	39.167 a	0.676 a	0.572 a	1.248 a	84.605 a
I ₂	39.205 a	0.696 a	0.590 a	1.286 a	84.624 a
I ₃	39.270 a	0.738 a	0.624 a	1.362 a	84.706 a
CV (%)	5.673	13.879	3.680	13.485	2.062

At specific days after sowing, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

Table 34a: Effect of variety on plant height, dry weights and leaf area of wheat at tillering stage (2014-15)

Variety	Plant height(cm)	Leaf dry weight plant ⁻¹ (g)	Stem dry weight plant ⁻¹ (g)	Total dry weight plant ⁻¹ (g)	Leaf area plant ⁻¹ (cm ²)
V ₁	37.303 a	0.694 a	0.595 a	1.289 a	82.096 a
V ₂	37.182 a	0.614 b	0.523 b	1.137 b	81.586 a
CV (%)	5.673	13.206	3.682	12.484	2.062

At specific days after sowing, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

Table 34b: Effect of variety on plant height, dry weights and leaf area of wheat at tillering stage (2015-16)

Variety	Plant height(cm)	Leaf dry weight plant ⁻¹ (g)	Stem dry weight plant ⁻¹ (g)	Total dry weight plant ⁻¹ (g)	Leaf area plant ⁻¹ (cm ²)
V ₁	38.020 a	0.707 a	0.607 a	1.314 a	83.466 a
V ₂	37.898 a	0.625 b	0.533 b	1.158 b	82.947 a
CV (%)	5.673	13.879	3.680	13.485	2.062

At specific days after sowing, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

Table 35a: Effect of nitrogen on plant height, dry weights and leaf area of wheat at tillering stage (2014-15)

Nitrogen	Plant height(cm)	Leaf dry weight plant ⁻¹ (g)	Stem dry weight plant ⁻¹ (g)	Total dry weight plant ⁻¹ (g)	Leaf area plant ⁻¹ (cm ²)
N ₀	29.594 b	0.494 b	0.429 b	0.923 b	60.189 c
N ₁	40.671 a	0.730 a	0.621 a	1.351 a	93.174 a
N ₂	39.766 a	0.712 a	0.602 a	1.315 a	87.910 b
N ₃	38.939 a	0.679 a	0.584 a	1.263 a	86.092 b
CV (%)	5.673	13.206	3.682	12.484	2.062

At specific days after sowing, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

Table 35b: Effect of nitrogen on plant height, dry weights and leaf area of wheat at tillering stage (2015-16)

Nitrogen	Plant height(cm)	Leaf dry weight plant ⁻¹ (g)	Stem dry weight plant ⁻¹ (g)	Total dry weight plant ⁻¹ (g)	Leaf area plant ⁻¹ (cm ²)
N ₀	30.163 b	0.503 b	0.437 b	0.940 b	61.191 c
N ₁	41.453 a	0.744 a	0.633 a	1.377 a	94.730 a
N ₂	40.531 a	0.726 a	0.614 a	1.340 a	89.377 b
N ₃	39.689 a	0.692 a	0.595 a	1.287 a	87.529 b
CV (%)	5.673	13.879	3.680	13.485	2.062

At specific days after sowing, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

Table 36a: Interaction effect of irrigation and nitrogen on plant height, dry weights and leaf area of wheat at tillering stage (2014-15)

Interaction (Irrigation × Nitrogen)	Plant height(cm)	Leaf dry weight plant ⁻¹ (g)	Stem dry weight plant ⁻¹ (g)	Total dry weight plant ⁻¹ (g)	Leaf area plant ⁻¹ (cm ²)
I ₀ N ₀	28.254 g	0.398 f	0.342 h	0.739 e	53.960 h
I ₀ N ₁	36.111 d	0.609 b-d	0.544 b-f	1.153 bc	90.148 b
I ₀ N ₂	35.154 e	0.597 cd	0.534 c-f	1.131 bc	83.555 f
I ₀ N ₃	34.677 e	0.571 de	0.514 d-f	1.085 c	81.982 f
I ₁ N ₀	29.749 f	0.478 ef	0.415gh	0.893 de	62.050 g
I ₁ N ₁	42.191 a	0.750 a	0.632 ab	1.382 a	94.296 a
I ₁ N ₂	41.330 b	0.734 a	0.607 a-c	1.341 a	89.239 b-d
I ₁ N ₃	40.442 c	0.693 a-c	0.592 a-e	1.285 ab	87.277 e
I ₂ N ₀	30.091 f	0.514 de	0.455 fg	0.970 cd	62.288 g
I ₂ N ₁	42.223 a	0.764 a	0.641 a	1.404 a	94.056 a
I ₂ N ₂	41.170 b	0.745 a	0.619 a-c	1.364 a	89.375 b-d
I ₂ N ₃	40.373 c	0.711 ab	0.602 a-d	1.313 ab	87.593 c-e
I ₃ N ₀	30.281 f	0.585 d	0.505 e-g	1.090 c	62.457 g
I ₃ N ₁	42.158 a	0.797 a	0.668 a	1.465 a	94.195 a
I ₃ N ₂	41.410 b	0.774 a	0.647 a	1.422 a	89.469 bc
I ₃ N ₃	40.266 c	0.741 a	0.629 ab	1.370 a	87.515 de
CV (%)	5.673	13.206	3.682	12.484	2.062

At specific days after sowing, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

Table 36b: Interaction effect of irrigation and nitrogen on plant height, dry weights and leaf area of wheat at tillering stage (2015-16)

Interaction (Irrigation × Nitrogen)	Plant height(cm)	Leaf dry weight plant ⁻¹ (g)	Stem dry weight plant ⁻¹ (g)	Total dry weight plant ⁻¹ (g)	Leaf area plant ⁻¹ (cm ²)
I ₀ N ₀	28.798 g	0.405 f	0.348 h	0.753 e	54.991 h
I ₀ N ₁	36.806 d	0.620 b-d	0.554 b-f	1.174 bc	91.871 b
I ₀ N ₂	35.831 e	0.608 cd	0.544 c-f	1.152 bc	85.152 f
I ₀ N ₃	35.345 e	0.582 de	0.524 d-f	1.106 c	83.549 f
I ₁ N ₀	30.322 f	0.487 ef	0.423 gh	0.910 de	63.086 g
I ₁ N ₁	43.002 a	0.765 a	0.644 ab	1.409 a	95.871 a
I ₁ N ₂	42.125 b	0.748 a	0.619 a-d	1.367 a	90.730 b-d
I ₁ N ₃	41.219 c	0.706 a-c	0.603 a-e	1.309 ab	88.735 e
I ₂ N ₀	30.670 f	0.524 de	0.464 fg	0.988 cd	63.257 g
I ₂ N ₁	43.036 a	0.778 a	0.653 a	1.431 a	95.519 a
I ₂ N ₂	41.963 b	0.759 a	0.631 a-c	1.390 a	90.765 b-d
I ₂ N ₃	41.150 c	0.724 ab	0.614 a-d	1.338 ab	88.956 c-e
I ₃ N ₀	30.863 f	0.596 d	0.515 e-g	1.111 c	63.428 g
I ₃ N ₁	42.968 a	0.812 a	0.681 a	1.493 a	95.660 a
I ₃ N ₂	42.206 b	0.789 a	0.660 a	1.449 a	90.861 bc
I ₃ N ₃	41.040 c	0.755 a	0.641 ab	1.396 a	88.876 de
CV (%)	5.673	13.879	3.680	13.485	2.062

At specific days after sowing, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

4.3.3. Booting stage

Irrigation treatments had significant influence on plant height, leaf dry weight plant⁻¹, stem dry weight plant⁻¹, total dry weight plant⁻¹ and leaf area plant⁻¹ at booting stage in both the years and are presented in Table 37a for first year (2014-15) and Table 37b for second year (2015-16). The highest plant height, leaf dry weight plant⁻¹, stem dry weight plant⁻¹, total dry weight plant⁻¹ and leaf area plant⁻¹ were observed in three irrigations (I₃) and the lowest values were found in rain-fed (I₀) condition in both the years. This finding was supported by Wu *et al.* (2011) who obtained increased plant height with increasing number of irrigations. Sher and Parvender (2006) reported that dry matter accumulation increased with increasing irrigation levels. Alam *et al.* (2003) reported that three irrigation were exhibited the highest value of plant height, leaf area. Mollah and paul (2011) stated that plant height increased with the increase of irrigation in barley. Similar result was reported in wheat (Pandit *et al.*, 2001, Rahman *et al.*, 2001 and Naeem Sarwar 2010). Abdorrahmani *et al.* (2005) reported that two irrigations produced highest TDM and moisture stress reduced TDM production. Ashok and Sharma (2004) observed that the irrigation treatments increased TDM. Similar result was reported in wheat (Nahar and Paul 1998, Rahman *et al.*, 2001 and Shen *et al.*, 2001).

Plant height, leaf dry weight plant⁻¹, stem dry weight plant⁻¹, total dry weight plant⁻¹ and leaf area plant⁻¹ did not differ significantly due to varieties at booting stage in both the years and are shown in Table 38a for first year (2014-15) and in Table 38b for second year (2015-16). Between the two varieties, higher plant height, leaf dry weight plant⁻¹, stem dry weight plant⁻¹, total dry weight plant⁻¹ and leaf area plant⁻¹ were observed in BARI Gom 24 (V1) at booting stage in both the years.

Plant height, leaf dry weight plant⁻¹, stem dry weight plant⁻¹, total dry weight plant⁻¹ and leaf area plant⁻¹ in both the years varied significantly due to split applications of nitrogen at booting stage and are presented in Table 39a for first year (2014-15) and in Table 39b for second year (2015-16). The highest Plant height, leaf dry weight plant⁻¹, stem dry weight plant⁻¹, total dry weight plant⁻¹ and leaf area plant⁻¹ were obtained in three splits (N₂) application of nitrogen in both the years. The results were statistically identical to basal (N₁) and four (N₃) splits application of nitrogen for plant height and leaf area plant⁻¹. The lowest plant height, leaf dry weight plant⁻¹, stem dry weight plant⁻¹, total dry weight plant⁻¹ and leaf area plant⁻¹ were found in control (N₀) in both the years. Ananda (2004) reported that split application of nitrogen recorded maximum plant height of wheat. Dry matter accumulation at all the stages increased with increasing levels of nitrogen (Chanda and Gunri, 2004).

Table 37a: Effect of irrigation on plant height, dry weights and leaf area of wheat at booting stage (2014-15)

Irrigation	Plant height(cm)	Leaf dry weight plant ⁻¹ (g)	Stem dry weight plant ⁻¹ (g)	Total dry weight plant ⁻¹ (g)	Leaf area plant ⁻¹ (cm ²)
I ₀	64.502 c	2.326 c	2.842 c	5.168 c	238.534 a
I ₁	69.449 bc	2.594 b	3.055 bc	5.649 b	240.472 a
I ₂	73.780 ab	2.719 ab	3.272 ab	5.992 ab	255.049 a
I ₃	75.148 a	2.828 a	3.358 a	6.185 a	261.109 a
CV (%)	3.749	5.557	5.305	3.483	15.528

At specific days after sowing, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

Table 37b: Effect of irrigation on plant height, dry weights and leaf area of wheat at booting stage (2015-16)

Irrigation	Plant height(cm)	Leaf dry weight plant ⁻¹ (g)	Stem dry weight plant ⁻¹ (g)	Total dry weight plant ⁻¹ (g)	Leaf area plant ⁻¹ (cm ²)
I ₀	65.710 c	2.367 c	2.893 c	5.260 c	243.070 a
I ₁	70.767 bc	2.637 b	3.110 bc	5.748 b	244.607 a
I ₂	75.172 ab	2.768 ab	3.330 ab	6.098 ab	259.591 a
I ₃	76.562 a	2.876 a	3.417 a	6.293 a	265.724 a
CV (%)	3.749	5.808	5.306	3.483	15.537

At specific days after sowing, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

Table 38a: Effect of variety on plant height, dry weights and leaf area of wheat at booting stage (2014-15)

Variety	Plant height(cm)	Leaf dry weight plant ⁻¹ (g)	Stem dry weight plant ⁻¹ (g)	Total dry weight plant ⁻¹ (g)	Leaf area plant ⁻¹ (cm ²)
V ₁	70.719 a	2.657 a	3.168 a	5.825 a	245.118 a
V ₂	70.721 a	2.577 a	3.095 a	5.672 a	252.464 a
CV (%)	3.749	5.557	5.305	3.483	15.528

At specific days after sowing, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

Table 38b: Effect of variety on plant height, dry weights and leaf area of wheat at booting stage (2015-16)

Variety	Plant height(cm)	Leaf dry weight plant ⁻¹ (g)	Stem dry weight plant ⁻¹ (g)	Total dry weight plant ⁻¹ (g)	Leaf area plant ⁻¹ (cm ²)
V ₁	72.052 a	2.703 a	3.224 a	5.927 a	249.496 a
V ₂	72.054 a	2.621 a	3.151 a	5.772 a	257.000 a
CV (%)	3.749	5.808	5.306	3.483	15.537

At specific days after sowing, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

Table 39a: Effect of nitrogen on plant height, dry weights and leaf area of wheat at booting stage (2014-15)

Nitrogen	Plant height(cm)	Leaf dry weight plant ⁻¹ (g)	Stem dry weight plant ⁻¹ (g)	Total dry weight plant ⁻¹ (g)	Leaf area plant ⁻¹ (cm ²)
N ₀	59.713 b	2.142 c	2.590 c	4.732 c	179.033 b
N ₁	73.724 a	2.695 b	3.226 b	5.921 b	271.007 a
N ₂	76.131 a	2.893 a	3.430 a	6.323 a	277.871 a
N ₃	73.312 a	2.737 b	3.281 ab	6.017 ab	267.253 a
CV (%)	3.749	5.557	5.305	3.483	15.528

At specific days after sowing, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

Table 39b: Effect of nitrogen on plant height, dry weights and leaf area of wheat at booting stage (2015-16)

Nitrogen	Plant height(cm)	Leaf dry weight plant ⁻¹ (g)	Stem dry weight plant ⁻¹ (g)	Total dry weight plant ⁻¹ (g)	Leaf area plant ⁻¹ (cm ²)
N ₀	60.838 b	2.179 c	2.636 c	4.815 c	182.240 b
N ₁	75.113 a	2.742 b	3.283 b	6.025 b	275.863 a
N ₂	77.566 a	2.943 a	3.491 a	6.435 a	282.850 a
N ₃	74.694 a	2.784 b	3.340 ab	6.123 ab	272.041 a
CV (%)	3.749	5.808	5.306	3.483	15.537

At specific days after sowing, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

Table 40a: Interaction effect of irrigation and nitrogen on plant height, dry weights and leaf area of wheat at booting stage (2014-15)

Interaction (Irrigation × Nitrogen)	Plant height (cm)	Leaf dry weight plant ⁻¹ (g)	Stem dry weight plant ⁻¹ (g)	Total dry weight plant ⁻¹ (g)	Leaf area plant ⁻¹ (cm ²)
I ₀ N ₀	55.420 l	1.969 h	2.366 k	4.335 j	171.230 g
I ₀ N ₁	66.893 h	2.408 f	2.890 h	5.297 f	261.023 ef
I ₀ N ₂	68.793 g	2.527 e	3.077 fg	5.604 e	265.313 c-f
I ₀ N ₃	66.902 h	2.399 f	3.035 g	5.434 ef	256.568 f
I ₁ N ₀	59.159 k	2.103 g	2.543 j	4.646 i	181.223 g
I ₁ N ₁	71.937 f	2.712 d	3.130 ef	5.842 d	261.052 ef
I ₁ N ₂	75.414 e	2.846 c	3.334 d	6.180 c	263.693 d-f
I ₁ N ₃	71.287 f	2.715 d	3.211 e	5.926 d	255.921 f
I ₂ N ₀	61.510 j	2.186 g	2.688 i	4.874 h	180.820 g
I ₂ N ₁	77.690 c	2.851 c	3.410 b-d	6.261 c	277.328 a-e
I ₂ N ₂	79.179 b	3.008 b	3.611 a	6.619 b	287.401 ab
I ₂ N ₃	76.742 d	2.831 c	3.382 cd	6.213 c	274.649 b-f
I ₃ N ₀	62.762 i	2.309 f	2.763 i	5.072 g	182.859 g
I ₃ N ₁	78.374 bc	2.808 cd	3.474 bc	6.282 c	284.625 a-c
I ₃ N ₂	81.140 a	3.192 a	3.699 a	6.891 a	295.078 a
I ₃ N ₃	78.316 bc	3.001 b	3.495 b	6.497 b	281.873 a-d
CV (%)	3.749	5.557	5.305	3.483	15.528

At specific days after sowing, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

Table 40b: Interaction effect of irrigation and nitrogen on plant height, dry weights and leaf area of wheat at booting stage (2015-16)

Interaction (Irrigation × Nitrogen)	Plant height(cm)	Leaf dry weight plant ⁻¹ (g)	Stem dry weight plant ⁻¹ (g)	Total dry weight plant ⁻¹ (g)	Leaf area plant ⁻¹ (cm ²)
I ₀ N ₀	56.458 l	2.004 h	2.408 k	4.412 j	174.488 g
I ₀ N ₁	68.146 h	2.450 f	2.941 h	5.391 f	265.988 ef
I ₀ N ₂	70.081 g	2.571 e	3.132 fg	5.703 e	270.358 c-f
I ₀ N ₃	68.155 h	2.441 f	3.090 g	5.531 ef	261.447 f
I ₁ N ₀	60.282 k	2.138 g	2.590 j	4.728 i	184.339 g
I ₁ N ₁	73.302 f	2.758 d	3.187 ef	5.945 d	265.541 ef
I ₁ N ₂	76.845 e	2.894 c	3.395 d	6.289 c	268.227 d-f
I ₁ N ₃	72.639 f	2.761 d	3.269 e	6.030 d	260.322 f
I ₂ N ₀	62.670 j	2.225 g	2.735 i	4.960 h	184.040 g
I ₂ N ₁	79.156 c	2.902 c	3.470 b-d	6.372 c	282.266 a-e
I ₂ N ₂	80.673 b	3.062 b	3.674 a	6.736 b	292.518 ab
I ₂ N ₃	78.190 d	2.881 c	3.442 cd	6.323 c	279.539 b-f
I ₃ N ₀	63.943 i	2.348 f	2.811 i	5.159 g	186.091 g
I ₃ N ₁	79.848 bc	2.856 cd	3.535 bc	6.391 c	289.657 a-c
I ₃ N ₂	82.666 a	3.247 a	3.764 a	7.011 a	300.294 a
I ₃ N ₃	79.790 c	3.053 b	3.557 b	6.610 b	286.856 a-d
CV (%)	3.749	5.808	5.306	3.483	15.537

At specific days after sowing, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

Khursheed and Mahammad (2015) reported that N fertilizer significantly increased plant height, shoot dry weight and leaf area. Chaturvedi (2006) reported that plant height and TDM increased with increasing nitrogen availability at all critical stages. Wagan *et al.* (2002) reported that nitrogen applied in three split doses significantly increased plant height. Shehzad *et al.* (2012) reported that all treatments significantly enhanced the plant height over the control.

Different treatment combinations of irrigation and nitrogen had significant influence on plant height, leaf dry weight plant⁻¹, stem dry weight plant⁻¹, total dry weight plant⁻¹ and leaf area plant⁻¹ at booting stage in both the years and are shown in Table 40a for first year (2014-15) and in Table 40b for second year (2015-16). The highest plant height, leaf dry weight plant⁻¹, stem dry weight plant⁻¹, total dry weight plant⁻¹ and leaf area plant⁻¹ at booting stage were observed in the treatment combination of three irrigations (I₃) × three split (N₂) applications of nitrogen and the lowest values were found in rain-fed (I₀) × control (N₀) in both the years.

4.3.4. Heading stage

Irrigation treatments had significant effect on plant height, leaf dry weight plant⁻¹, stem dry weight plant⁻¹, total dry weight plant⁻¹ and leaf area plant⁻¹ at panicle initiation stage in both the years and are presented in Table 41a for first year (2014-15) and Table 41b for second year (2015-16). With a few exceptions, the highest plant height, leaf dry weight plant⁻¹, stem dry weight plant⁻¹, total dry weight plant⁻¹ and leaf area plant⁻¹ at heading stage were obtained in three irrigations (I₃) in both the years and the lowest values were observed in rain-fed (I₀) condition in both the years Plant height increased with increasing of irrigations. Similar result was reported in wheat (Ali and Amin, 2007). Dry matter accumulation increased with increasing irrigation levels. Similar result was found in wheat (Abdorrahamani *et al.*, 2005). Alam *et al.* (2003) reported that three irrigation were exhibited the highest value of plant height, leaf area. Mollah and Paul (2011) stated that plant height increased with the increase of irrigation in barley. Similar result was reported in wheat (Pandit *et al.*, 2001 and Naeem Sarwar 2010). Pal and Upasani (2007) observed that four irrigations produced highest TDM than other irrigation treatments. Abdorrahamani *et al.* (2005) reported that two irrigations produced highest TDM and moisture stress reduced TDM production. Ashok and Sharma (2004) observed that the irrigation treatments increased TDM. Similar result was reported in wheat (Sarker and Paul 1997, Rahman *et al.*, 2001 and Shen *et al.*, 2001).

Varieties had no significant effect on plant height, leaf dry weight plant⁻¹, stem dry weight plant⁻¹, total dry weight plant⁻¹ and leaf area plant⁻¹ at panicle initiation stage in both the years and are presented in Table 42a for first year (2014-15) and in Table 42b for second year (2015-16). Between the two varieties, higher plant height, leaf dry weight plant⁻¹, stem dry weight plant⁻¹, total dry weight plant⁻¹ and leaf area plant⁻¹ were observed in BARI Gom 24 (V1) at heading stage in both the years.

Plant height, leaf dry weight plant⁻¹, stem dry weight plant⁻¹, total dry weight plant⁻¹ and leaf area plant⁻¹ were significantly influenced by split applications of nitrogen at heading stage in both the years and are presented in Table 43a for first year (2014-15) and in Table 43b for second year (2015-16). The highest Plant height, leaf dry weight plant⁻¹, stem dry weight plant⁻¹, total dry weight plant⁻¹ and leaf area plant⁻¹ were produced in three splits (N₂) application of nitrogen and the lowest values were obtained in control (N₀) in both the years. Khursheed and Mahammad (2015) reported that N fertilizer significantly increased plant height, shoot dry weight and leaf area. Chaturvedi (2006) reported that plant height and TDM increased with increasing nitrogen availability at all critical stages. Ananda (2004) reported that split application of nitrogen as three split recorded maximum plant height of wheat. Wagan *et al.* (2002) reported that nitrogen applied in three split doses significantly increased plant height. Shehzad *et al.* (2012) reported that all treatments significantly enhanced the plant height over the control.

Plant height, leaf dry weight plant⁻¹, stem dry weight plant⁻¹, total dry weight plant⁻¹ and leaf area plant⁻¹ at heading stage varied significantly due to the interaction of irrigation and nitrogen in both the years and are shown in Table 44a for first year (2014-15) and in Table 44b for second year (2015-16). The highest Plant height, leaf dry weight plant⁻¹, stem dry weight plant⁻¹, total dry weight plant⁻¹ and leaf area plant⁻¹ at heading stage were produced in the treatment combination of three irrigations (I₃) × three split (N₂) applications of nitrogen in both the years. The results were statistically similar with two irrigations (I₂) × three split (N₂) applications of nitrogen for stem dry weight plant⁻¹ in the second year (2015-16). The lowest plant height, leaf dry weight plant⁻¹, stem dry weight plant⁻¹, total dry weight plant⁻¹ and leaf area plant⁻¹ were observed in rain-fed (I₀) × control (N₀) in both the years.

Table 41a: Effect of irrigation on plant height, dry weights and leaf area of wheat at heading stage (2014-15)

Irrigation	Plant height(cm)	Leaf dry weight plant ⁻¹ (g)	Stem dry weight plant ⁻¹ (g)	Spike dry weight plant ⁻¹ (g)	Total dry weight plant ⁻¹ (g)	Leaf area plant ⁻¹ (cm ²)
I ₀	68.498 b	2.458 c	2.854 c	0.290 b	5.602 c	250.480 a
I ₁	72.954 b	2.770 b	3.067 bc	0.294 b	6.131bc	250.752 a
I ₂	79.183 a	2.921 ab	3.285 ab	0.330 ab	6.536 ab	264.948 a
I ₃	81.952 a	3.073 a	3.370 a	0.400 a	6.843 a	271.993 a
CV (%)	3.514	5.463	5.285	7.805	3.212	15.032

At specific days after sowing, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

Table 41b: Effect of irrigation on plant height, dry weights and leaf area of wheat at heading stage (2015-16)

Irrigation	Plant height(cm)	Leaf dry weight plant ⁻¹ (g)	Stem dry weight plant ⁻¹ (g)	Spike dry weight plant ⁻¹ (g)	Total dry weight plant ⁻¹ (g)	Leaf area plant ⁻¹ (cm ²)
I ₀	69.642 b	2.479 c	2.905 c	0.303 b	5.688 c	252.612 a
I ₁	74.165 b	2.794 b	3.122 bc	0.291 b	6.207 bc	252.886 a
I ₂	80.417 a	2.946 ab	3.343 ab	0.333 ab	6.622 ab	267.204 a
I ₃	83.262 a	3.098 a	3.429 a	0.374 a	6.901 a	274.308 a
CV (%)	3.521	5.452	5.274	7.653	3.206	15.028

At specific days after sowing, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

Table 42a: Effect of variety on plant height, dry weights and leaf area of wheat at heading stage (2014-15)

Variety	Plant height(cm)	Leaf dry weight plant ⁻¹ (g)	Stem dry weight plant ⁻¹ (g)	Spike dry weight plant ⁻¹ (g)	Total dry weight plant ⁻¹ (g)	Leaf area plant ⁻¹ (cm ²)
V ₁	75.646 a	2.846 a	3.180 a	0.329 a	6.355 a	255.822 a
V ₂	75.648 a	2.765 a	3.108 a	0.329 a	6.201 a	263.264 a
CV (%)	3.514	5.463	5.285	7.805	3.212	15.032

At specific days after sowing, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

Table 42b: Effect of variety on plant height, dry weights and leaf area of wheat at heading stage (2015-16)

Variety	Plant height(cm)	Leaf dry weight plant ⁻¹ (g)	Stem dry weight plant ⁻¹ (g)	Spike dry weight plant ⁻¹ (g)	Total dry weight plant ⁻¹ (g)	Leaf area plant ⁻¹ (cm ²)
V ₁	76.870 a	2.870 a	3.237 a	0.325 a	6.432 a	258.000 a
V ₂	76.873 a	2.789 a	3.163 a	0.325 a	6.277 a	265.505 a
CV (%)	3.521	5.452	5.274	7.653	3.206	15.028

At specific days after sowing, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

Table 43a: Effect of nitrogen on plant height, dry weights and leaf area of wheat at heading stage (2014-15)

Nitrogen	Plant height (cm)	Leaf dry weight plant ⁻¹ (g)	Stem dry weight plant ⁻¹ (g)	Spike dry weight plant ⁻¹ (g)	Total dry weight plant ⁻¹ (g)	Leaf area plant ⁻¹ (cm ²)
N ₀	64.447 b	2.246 c	2.602 c	0.152 c	5.000 c	188.539 b
N ₁	79.298 a	2.927 b	3.238 b	0.350 b	6.515 b	281.962 a
N ₂	81.027 a	3.117 a	3.443 a	0.413 a	6.973 a	288.837 a
N ₃	77.815 a	2.932 ab	3.293 ab	0.399 a	6.624 b	278.834 a
CV (%)	3.514	5.463	5.285	7.805	3.212	15.032

At specific days after sowing, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

Table 43b: Effect of nitrogen on plant height, dry weights and leaf area of wheat at heading stage (2015-16)

Nitrogen	Plant height(cm)	Leaf dry weight plant ⁻¹ (g)	Stem dry weight plant ⁻¹ (g)	Spike dry weight plant ⁻¹ (g)	Total dry weight plant ⁻¹ (g)	Leaf area plant ⁻¹ (cm ²)
N ₀	65.493 b	2.265 c	2.648 c	0.148 c	5.061 c	190.144 b
N ₁	80.581 a	2.952 b	3.296 b	0.347 b	6.595 b	284.362 a
N ₂	82.339 a	3.143 a	3.504 a	0.410 a	7.057 a	291.295 a
N ₃	79.074 a	2.957 ab	3.352 ab	0.396 a	6.705 b	281.208 a
CV (%)	3.521	5.452	5.274	7.653	3.206	15.028

At specific days after sowing, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

Table 44a: Interaction effect of irrigation and nitrogen on plant height, dry weights and leaf area of wheat at heading stage (2014-15)

Interaction (Irrigation × Nitrogen)	Plant height (cm)	Leaf dry weight plant ⁻¹ (g)	Stem dry weight plant ⁻¹ (g)	Spike dry weight plant ⁻¹ (g)	Total dry weight plant ⁻¹ (g)	Leaf area plant ⁻¹ (cm ²)
I ₀ N ₀	61.370 k	2.081 i	2.378 k	0.123 o	4.583 i	180.286 e
I ₀ N ₁	71.333 h	2.516 f	2.902 h	0.252 k	5.861 f	273.823 cd
I ₀ N ₂	70.573 h	2.720 e	3.090 fg	0.367 g	6.151 e	278.818 b-d
I ₀ N ₃	70.715 h	2.517 f	3.048 g	0.268 j	5.833 f	268.991 cd
I ₁ N ₀	63.820 j	2.210 h	2.556 j	0.132 n	4.935 h	190.336 e
I ₁ N ₁	75.963 f	2.913 d	3.142 ef	0.342 h	6.426 d	272.058 cd
I ₁ N ₂	78.415 e	3.066 c	3.346 d	0.419 e	6.779 c	276.043 b-d
I ₁ N ₃	73.618 g	2.893 d	3.223 e	0.371 f	6.369 d	264.570 d
I ₂ N ₀	64.413 j	2.286 h	2.700 i	0.170 m	5.118 h	190.255 e
I ₂ N ₁	84.737 c	3.073 c	3.422 b-d	0.341 i	6.837 c	287.485 a-c
I ₂ N ₂	86.080 b	3.251 b	3.623 a	0.460 b	7.302 b	294.793 ab
I ₂ N ₃	81.500 d	3.072 c	3.394 cd	0.443 c	6.886 c	287.261 a-c
I ₃ N ₀	68.183 i	2.406 g	2.775 i	0.185 l	5.366 g	193.280 e
I ₃ N ₁	85.160 c	3.206 b	3.486 bc	0.428 d	7.187 b	294.483 ab
I ₃ N ₂	89.040 a	3.430 a	3.711 a	0.494 a	7.601 a	305.692 a
I ₃ N ₃	85.426 bc	3.248 b	3.508 b	0.461 b	7.217 b	294.516 ab
CV (%)	3.514	5.463	5.285	7.805	3.212	15.032

At specific days after sowing, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

Table 44b: Interaction effect of irrigation and nitrogen on plant height, dry weights and leaf area of wheat at heading stage (2015-16)

Interaction (Irrigation × Nitrogen)	Plant height(cm)	Leaf dry weight plant ⁻¹ (g)	Stem dry weight plant ⁻¹ (g)	Spike dry weight plant ⁻¹ (g)	Total dry weight plant ⁻¹ (g)	Leaf area plant ⁻¹ (cm ²)
I ₀ N ₀	62.398 k	2.099 i	2.420 k	0.129 o	4.648 i	181.821 e
I ₀ N ₁	72.526 h	2.537 f	2.953 h	0.252 k	5.946 f	276.154 cd
I ₀ N ₂	71.751 h	2.743 e	3.145 fg	0.368 g	6.239 e	281.191 b-d
I ₀ N ₃	71.895 h	2.538 f	3.102 g	0.278 j	5.918 f	271.280 cd
I ₁ N ₀	64.882 j	2.229 h	2.602 j	0.132 n	5.000 h	191.956 e
I ₁ N ₁	77.222 f	2.938 d	3.199 ef	0.352 h	6.510 d	274.374 cd
I ₁ N ₂	79.715 e	3.093 c	3.407 d	0.424 e	6.868 c	278.393 b-d
I ₁ N ₃	74.839 g	2.918 d	3.282 e	0.373 f	6.451 d	266.822 d
I ₂ N ₀	65.420 j	2.306 h	2.747 i	0.163 m	5.185 h	191.874 e
I ₂ N ₁	86.056 c	3.100 c	3.482 b-d	0.345 i	6.927 c	289.932 a-c
I ₂ N ₂	87.423 b	3.279 b	3.686 a	0.435 c	7.398 b	297.302 ab
I ₂ N ₃	82.770 d	3.098 c	3.454 cd	0.433 d	6.976 c	289.706 a-c
I ₃ N ₀	69.273 i	2.426 g	2.824 i	0.169 l	5.413 g	194.925 e
I ₃ N ₁	86.518 c	3.233 b	3.547 bc	0.433 d	7.249 b	296.990 ab
I ₃ N ₂	90.466 a	3.459 a	3.776 a	0.469 a	7.668 a	308.294 a
I ₃ N ₃	86.790 bc	3.276 b	3.569 b	0.456 b	7.280 b	297.023 ab
CV (%)	3.521	5.452	5.274	7.653	3.206	15.028

At specific days after sowing, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

4.3.5. Anthesis stage

Plant height, leaf dry weight plant⁻¹, stem dry weight plant⁻¹, total dry weight plant⁻¹ and leaf area plant⁻¹ were influenced significantly by different levels of irrigation at anthesis stage in both the years and are presented in Table 45a for first year (2014-15) and in Table 45b for second year (2015-16). The highest plant height, leaf dry weight plant⁻¹, stem dry weight plant⁻¹, total dry weight plant⁻¹ and leaf area plant⁻¹ at anthesis stage were observed in three irrigations (I₃) and the lowest values were found in rain-fed (I₀) condition in both the years. Islam (1997) reported that plant height increased with increasing number of irrigations. Ashok and Sharma (2004) observed that the irrigation treatments increased dry matter accumulation. Alam *et al.* (2003) reported that three irrigation were exhibited the highest value of plant height, leaf area. Mollah and Paul (2011) stated that plant height increased with the increase of irrigation. Similar result was reported in wheat (Pandit *et al.*, 2001, Rahman *et al.*, 2001 and Naeem Sarwar 2010). Pal and Upasani (2007) observed that four irrigations produced highest TDM than other irrigation treatments. Abdorrahmani *et al.* (2005) reported that two irrigations produced highest TDM and moisture stress reduced TDM production. Ashok and Sharma (2004) observed that the irrigation treatments increased TDM. Similar result was reported in wheat (Sarker and Paul 1997, Rahman *et al.*, 2001 and Shen *et al.*, 2001).

Plant height, leaf dry weight plant⁻¹, stem dry weight plant⁻¹, total dry weight plant⁻¹ and leaf area plant⁻¹ did not differ significantly due to varieties at anthesis stage in both the years. It is shown in Table 46a for first year (2014-15) and in Table 46b for second year (2015-16). Between the two varieties, higher plant height, leaf dry weight plant⁻¹, stem dry weight plant⁻¹, total dry weight plant⁻¹ and leaf area plant⁻¹ were observed in BARI Gom 24 (V1) at booting stage in both the years.

Split applications of nitrogen had significant effect on plant height, leaf dry weight plant⁻¹, stem dry weight plant⁻¹, total dry weight plant⁻¹ and leaf area plant⁻¹ at anthesis stage in both the years and are presented in Table 47a for first year (2014-15) and in Table 47b for second year (2015-16). The highest Plant height, leaf dry weight plant⁻¹, stem dry weight plant⁻¹, total dry weight plant⁻¹ and leaf area plant⁻¹ were obtained in three splits (N₂) application of nitrogen and the lowest values were obtained in control (N₀) in both the years. Nitrogen nutrient encourages plant height, leaf dry weight plant⁻¹, stem dry weight plant⁻¹, total dry weight plant⁻¹ and leaf area plant⁻¹ and for this reason above parameters increased with the increase on nitrogen fertilizer, similar result was reported in wheat (Awasthi and Bhan, 1993). Khursheed and Mahammad (2015) reported that N fertilizer significantly increased

Table 45a: Effect of irrigation on plant height, dry weights and leaf area of wheat at anthesis stage (2014-15)

Irrigation	Plant height (cm)	Leaf dry weight plant ⁻¹ (g)	Stem dry weight plant ⁻¹ (g)	Spike dry weight plant ⁻¹ (g)	Total dry weight plant ⁻¹ (g)	Leaf area plant ⁻¹ (cm ²)
I ₀	77.134 c	2.587 c	3.267 c	1.203 c	7.057 c	261.063 a
I ₁	79.838 bc	2.865 b	3.479 bc	1.490 b	7.833 b	262.616 a
I ₂	84.626 ab	3.079 ab	3.697 ab	1.572 ab	8.349 ab	275.043 a
I ₃	87.952 a	3.229 a	3.782 a	1.723 a	8.735 a	281.162 a
CV (%)	3.924	5.146	4.672	7.393	2.511	14.516

At specific days after sowing, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

Table 45b: Effect of irrigation on plant height, dry weights and leaf area of wheat at anthesis stage (2015-16)

Irrigation	Plant height(cm)	Leaf dry weight plant ⁻¹ (g)	Stem dry weight plant ⁻¹ (g)	Spike dry weight plant ⁻¹ (g)	Total dry weight plant ⁻¹ (g)	Leaf area plant ⁻¹ (cm ²)
I ₀	78.041 c	2.607 c	3.317 c	1.228 c	7.152 c	263.028 a
I ₁	81.284 bc	2.890 b	3.535 bc	1.520 b	7.946 b	263.803 a
I ₂	86.251 ab	3.104 ab	3.755 ab	1.607 ab	8.466 ab	276.495 a
I ₃	89.626 a	3.256 a	3.841 a	1.760 a	8.858 a	283.058 a
CV (%)	3.934	5.214	4.682	7.587	2.514	14.487

At specific days after sowing, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

Table 46a: Effect of variety on plant height, dry weights and leaf area of wheat at anthesis stage (2014-15)

Variety	Plant height(cm)	Leaf dry weight plant ⁻¹ (g)	Stem dry weight plant ⁻¹ (g)	Spike dry weight plant ⁻¹ (g)	Total dry weight plant ⁻¹ (g)	Leaf area plant ⁻¹ (cm ²)
V ₁	82.635 a	2.981 a	3.593 a	1.494 a	8.067 a	266.273 a
V ₂	82.140 a	2.900 a	3.520 a	1.500 a	7.920 a	273.669 a
CV (%)	3.924	5.146	4.672	7.393	2.511	14.516

At specific days after sowing, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

Table 46b: Effect of variety on plant height, dry weights and leaf area of wheat at anthesis stage (2015-16)

Variety	Plant height(cm)	Leaf dry weight plant ⁻¹ (g)	Stem dry weight plant ⁻¹ (g)	Spike dry weight plant ⁻¹ (g)	Total dry weight plant ⁻¹ (g)	Leaf area plant ⁻¹ (cm ²)
V ₁	83.955 a	3.005 a	3.649 a	1.529 a	8.183 a	267.843 a
V ₂	83.646 a	2.923 a	3.575 a	1.529 a	8.028 a	275.348 a
CV (%)	3.934	5.214	4.682	7.587	2.514	14.487

At specific days after sowing, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

Table 47a: Effect of nitrogen on plant height, dry weights and leaf area of wheat at anthesis stage (2014-15)

Nitrogen	Plant height(cm)	Leaf dry weight plant ⁻¹ (g)	Stem dry weight plant ⁻¹ (g)	Spike dry weight plant ⁻¹ (g)	Total dry weight plant ⁻¹ (g)	Leaf area plant ⁻¹ (cm ²)
N ₀	71.748 c	2.425 c	3.015 c	1.122 c	6.562 c	196.630 c
N ₁	83.948 b	3.000 b	3.650 b	1.528 b	8.177 b	293.263 ab
N ₂	88.239 a	3.291 a	3.655 a	1.732 a	8.877 a	301.646 a
N ₃	85.615 ab	3.045 b	3.704 ab	1.606 ab	8.357 b	288.346 b
CV (%)	3.924	5.146	4.672	7.393	2.511	14.516

At specific days after sowing, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

Table 47b: Effect of nitrogen on plant height, dry weights and leaf area of wheat at anthesis stage (2015-16)

Nitrogen	Plant height(cm)	Leaf dry weight plant ⁻¹ (g)	Stem dry weight plant ⁻¹ (g)	Spike dry weight plant ⁻¹ (g)	Total dry weight plant ⁻¹ (g)	Leaf area plant ⁻¹ (cm ²)
N ₀	72.976 c	2.446 c	3.061 c	1.148 c	6.653 c	197.810 c
N ₁	85.388 b	3.024 b	3.708 b	1.560 b	8.292 b	295.029 ab
N ₂	89.755 a	3.318 a	3.916 a	1.768 a	9.002 a	303.461 a
N ₃	87.084 ab	3.070 b	3.764 ab	1.640 ab	8.474 b	290.083 b
CV (%)	3.934	5.214	4.682	7.587	2.514	14.487

At specific days after sowing, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

Table 48a: Interaction effect of irrigation and nitrogen on plant height, dry weights and leaf area of wheat at anthesis stage (2014-15)

Interaction (Irrigation × Nitrogen)	Plant height (cm)	Leaf dry weight plant ⁻¹ (g)	Stem dry weight plant ⁻¹ (g)	Spike dry weight plant ⁻¹ (g)	Total dry weight plant ⁻¹ (g)	Leaf area plant ⁻¹ (cm ²)
I ₀ N ₀	68.537 m	2.169 j	2.790 k	1.005 l	5.964 l	188.397 f
I ₀ N ₁	78.470 i	2.626 g	3.314 h	1.176 i	7.116 i	285.506 c-e
I ₀ N ₂	81.376 g	2.866 f	3.502 fg	1.412 f	7.781 g	291.005 b-e
I ₀ N ₃	80.152 h	2.687 g	3.460 g	1.220 h	7.367 h	279.346 e
I ₁ N ₀	69.928 l	2.360 i	2.968 j	1.024 k	6.352 k	198.061 f
I ₁ N ₁	81.497 fg	2.952 f	3.554 ef	1.534 e	8.040 f	284.588 de
I ₁ N ₂	85.332 e	3.195 de	3.759 d	1.734 c	8.687 d	290.414 b-e
I ₁ N ₃	82.597 f	2.952 f	3.636 e	1.667 d	8.254 e	277.401 e
I ₂ N ₀	72.858 k	2.504 h	3.112 i	1.143 j	6.759 j	198.492 f
I ₂ N ₁	86.884 d	3.143 e	3.834 b-d	1.659 d	8.636 d	297.528 a-e
I ₂ N ₂	90.929 b	3.491 b	4.035 a	1.742 c	9.268 b	308.341 ab
I ₂ N ₃	87.833 cd	3.180 de	3.806 d	1.745 c	8.731 d	295.812 b-e
I ₃ N ₀	75.670 j	2.668 g	3.188 i	1.317 g	7.173 i	201.566 f
I ₃ N ₁	88.940 c	3.275 cd	3.898 bc	1.743 c	8.916 c	305.430 a-c
I ₃ N ₂	95.319 a	3.612 a	4.123 a	2.039 a	9.774 a	316.824 a
I ₃ N ₃	91.878 b	3.361 c	3.919 b	1.794 b	9.075 c	300.827 a-d
CV (%)	3.924	5.146	4.672	7.393	2.511	14.516

At specific days after sowing, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

Table 48b: Interaction effect of irrigation and nitrogen on plant height, dry weights and leaf area of wheat at anthesis stage (2015-16)

Interaction (Irrigation × Nitrogen)	Plant height (cm)	Leaf dry weight plant ⁻¹ (g)	Stem dry weight plant ⁻¹ (g)	Spike dry weight plant ⁻¹ (g)	Total dry weight plant ⁻¹ (g)	Leaf area plant ⁻¹ (cm ²)
I ₀ N ₀	69.341 m	2.186 j	2.833 k	1.026 l	6.045 m	189.820 f
I ₀ N ₁	79.393 i	2.646 g	3.366 h	1.200 i	7.212 j	287.654 c-e
I ₀ N ₂	82.334 g	2.888 f	3.557 fg	1.440 f	7.885 h	293.191 b-e
I ₀ N ₃	81.095 h	2.708 g	3.514 g	1.244 h	7.467 i	281.447 e
I ₁ N ₀	71.195 l	2.381 i	3.014 j	1.047 k	6.443 l	198.956 f
I ₁ N ₁	82.972 g	2.979 f	3.611 ef	1.565 e	8.156 g	285.874 de
I ₁ N ₂	86.878 e	3.223 de	3.819 d	1.768 c	8.811 e	291.727 b-e
I ₁ N ₃	84.092 f	2.979 f	3.694 e	1.700 d	8.373 f	278.655 e
I ₂ N ₀	74.257 k	2.524 h	3.160 i	1.170 j	6.854 k	199.540 f
I ₂ N ₁	88.553 d	3.168 e	3.894 b-d	1.695 d	8.758 e	299.099 a-e
I ₂ N ₂	92.676 b	3.518 b	4.099 a	1.780 c	9.398 b	309.968 ab
I ₂ N ₃	89.520 d	3.204 de	3.866 cd	1.783 c	8.854 de	297.373 b-e
I ₃ N ₀	77.110 j	2.691 g	3.236 i	1.346 g	7.274 j	202.925 f
I ₃ N ₁	90.633 c	3.302 cd	3.959 bc	1.780 c	9.042 cd	307.490 a-c
I ₃ N ₂	97.133 a	3.643 a	4.188 a	2.081 a	9.913 a	318.961 a
I ₃ N ₃	93.627 b	3.390 c	3.981 b	1.832 b	9.204 c	302.856 a-d
CV (%)	3.934	5.214	4.682	7.587	2.514	14.487

At specific days after sowing, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

plant height, shoot dry weight and leaf area. Chaturvedi (2006) reported that plant height and TDM increased with increasing nitrogen availability at all critical stages. Ananda (2004) reported that split application of nitrogen as three split recorded maximum plant height of wheat. Wagan *et al.* (2002) reported that nitrogen applied in three split doses significantly increased plant height. Shehzad *et al.* (2012) reported that all treatments significantly enhanced the plant height over the control.

Different treatment combinations of irrigation and nitrogen had significant influence on plant height, leaf dry weight plant⁻¹, stem dry weight plant⁻¹, total dry weight plant⁻¹ and leaf area plant⁻¹ at anthesis stage in both the years and are shown in Table 48a for first year (2014-15) and in Table 48b for second year (2015-16). The highest Plant height, leaf dry weight plant⁻¹, stem dry weight plant⁻¹, total dry weight plant⁻¹ and leaf area plant⁻¹ at anthesis stage were observed in the treatment combination of three irrigations (I₃) × three splits (N₂) application of nitrogen and the lowest values were found in rain-fed (I₀) × control (N₀) in both the years.

4.3.6. Physiological maturity stage

Irrigation treatments had significant effect on plant height, leaf dry weight plant⁻¹, stem dry weight plant⁻¹, total dry weight plant⁻¹ and leaf area plant⁻¹ at physiological maturity stage in both the years and are presented in Table 49a for first year (2014-15) and in Table 49b for second year (2015-16). The highest plant height, leaf dry weight plant⁻¹, stem dry weight plant⁻¹, total dry weight plant⁻¹ and leaf area plant⁻¹ at physiological maturity stage were produced in three irrigations (I₃) in both the years. The results were statistically identical to two irrigations (I₂) for plant height in both the years. The lowest plant height, leaf dry weight plant⁻¹, stem dry weight plant⁻¹, total dry weight plant⁻¹ and leaf area plant⁻¹ at physiological maturity were observed in rain-fed (I₀) condition in both the years. Plant height increased with increasing number of irrigations. Similar result was found in wheat (Basunia, 2000). Dry matter accumulation increased with increasing irrigation levels. Similar result was obtained in wheat (Dong *et al.*, 2013). Mandal *et al.* (2002) reported that leaf area increased significantly with increasing levels of irrigation. Alam *et al.* (2003) reported that three irrigation were exhibited the highest value of plant height, leaf area. Mollah and Paul (2011) stated that plant height increased with the increase of irrigation in barley. Similar result was reported in wheat (Pandit *et al.*, 2001, Rahman *et al.*, 2001 and Naeem Sarwar 2010). Pal and Upasani (2007) observed that four irrigations produced highest TDM than other irrigation treatments. Abdorrahmani *et al.* (2005) reported that two irrigations produced highest TDM and moisture stress reduced TDM production. Ashok and Sharma (2004) observed that the irrigation

treatments increased TDM. Similar result was reported in wheat (Nahar and Paul 1998, Rahman *et al.*, 2001, Simane *et al.*, 1993 and Shen *et al.*, 2001).

Varieties had no significant effect on plant height, leaf dry weight plant⁻¹, stem dry weight plant⁻¹, total dry weight plant⁻¹ and leaf area plant⁻¹ at physiological maturity stage in both the years and are presented in Table 50a for first year (2014-15) and in Table 50b for second year (2015-16). Between the two varieties, higher plant height, leaf dry weight plant⁻¹, stem dry weight plant⁻¹, total dry weight plant⁻¹ and leaf area plant⁻¹ were observed in BARI Gom 24 (V1) at physiological maturity stage in both the years.

Plant height, leaf dry weight plant⁻¹, stem dry weight plant⁻¹, total dry weight plant⁻¹ and leaf area plant⁻¹ were influenced significantly by splits application of nitrogen at physiological maturity stage in both the years and are presented in Table 51a for first year (2014-15) and in Table 51b for second year (2015-16). The highest Plant height, leaf dry weight plant⁻¹, stem dry weight plant⁻¹, total dry weight plant⁻¹ and leaf area plant⁻¹ at physiological maturity stage were obtained in three splits (N₂) application of nitrogen and the lowest values were found in control (N₀) in both the years. The result revealed that nitrogen application in three split doses significantly increased plant height. This result is also supported by Wagan *et al.*, 2002. Bellido *et al.* (2000) reported that the amount of total dry matter was increased with increasing nitrogen fertilizer application. Khursheed and Mahammad (2015) reported that N fertilizer significantly increased plant height, shoot dry weight and leaf area. Ananda (2004) reported that split application of nitrogen as three split recorded maximum plant height of wheat. Wagan *et al.* (2002) reported that nitrogen applied in three split doses significantly increased plant height. Shehzad *et al.* (2012) reported that all treatments significantly enhanced the plant height over the control. Chaturvedi (2006) reported that plant height and TDM production increased with increasing nitrogen availability at all critical stages.

Plant height, leaf dry weight plant⁻¹, stem dry weight plant⁻¹, total dry weight plant⁻¹ and leaf area plant⁻¹ at physiological maturity stage varied significantly due to the interaction of irrigation and nitrogen in both the years and are shown in Table 52a for first year (2014-15) and in Table 52b for second year (2015-16). The highest plant height, leaf dry weight plant⁻¹, stem dry weight plant⁻¹, total dry weight plant⁻¹ and leaf area plant⁻¹ at physiological maturity stage were observed in the treatment combination of three irrigations (I₃) × three splits (N₂) application of nitrogen and the lowest values were found in rain-fed (I₀) × control (N₀) in both the years.

Table 49a: Effect of irrigation on plant height, dry weights and leaf area of wheat at physiological maturity stage (2014-15)

Irrigation	Plant height(cm)	Leaf dry weight plant ⁻¹ (g)	Stem dry weight plant ⁻¹ (g)	Spike dry weight plant ⁻¹ (g)	Total dry weight plant ⁻¹ (g)	Leaf area plant ⁻¹ (cm ²)
I ₀	85.695 b	1.468 c	3.816 d	3.361 b	8.644 c	183.537 b
I ₁	89.509 b	1.675 b	4.116 c	3.750 ab	9.540 bc	185.582 b
I ₂	96.146 a	1.788 ab	4.554 b	3.906 ab	10.248 ab	196.386 ab
I ₃	100.583 a	1.882 a	4.768 a	4.386 a	11.036 a	206.660 a
CV (%)	3.585	8.921	3.893	3.269	2.033	11.996

At specific days after sowing, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

Table 49b: Effect of irrigation on plant height, dry weights and leaf area of wheat at physiological maturity stage (2015-16)

Irrigation	Plant height(cm)	Leaf dry weight plant ⁻¹ (g)	Stem dry weight plant ⁻¹ (g)	Spike dry weight plant ⁻¹ (g)	Total dry weight plant ⁻¹ (g)	Leaf area plant ⁻¹ (cm ²)
I ₀	87.332 b	1.494 c	3.966 d	3.347 c	8.807 c	187.011b
I ₁	90.993 b	1.704 b	4.241 c	3.739 bc	9.684 bc	189.154 b
I ₂	97.543 a	1.818 ab	4.712 b	3.861 ab	10.391 ab	200.120 ab
I ₃	102.050 a	1.915 a	4.927 a	4.341 a	11.183 a	208.516 a
CV (%)	3.587	8.918	3.830	3.294	2.035	12.054

At specific days after sowing, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

Table 50a: Effect of variety on plant height, dry weights and leaf area of wheat at physiological maturity stage (2014-15)

Variety	Plant height(cm)	Leaf dry weight plant ⁻¹ (g)	Stem dry weight plant ⁻¹ (g)	Spike dry weight plant ⁻¹ (g)	Total dry weight plant ⁻¹ (g)	Leaf area plant ⁻¹ (cm ²)
V ₁	93.105 a	1.743 a	4.349 a	3.851 a	9.944 a	189.361 a
V ₂	92.862 a	1.663 a	4.278 a	3.850 a	9.791 a	196.722 a
CV (%)	3.585	8.921	3.893	3.269	2.033	11.996

At specific days after sowing, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

Table 50b: Effect of variety on plant height, dry weights and leaf area of wheat at physiological maturity stage (2015-16)

Variety	Plant height(cm)	Leaf dry weight plant ⁻¹ (g)	Stem dry weight plant ⁻¹ (g)	Spike dry weight plant ⁻¹ (g)	Total dry weight plant ⁻¹ (g)	Leaf area plant ⁻¹ (cm ²)
V ₁	94.603 a	1.774 a	4.498 a	3.822 a	10.094 a	192.448 a
V ₂	94.356 a	1.692 a	4.425 a	3.821 a	9.938 a	199.953 a
CV (%)	3.587	8.918	3.830	3.294	2.035	12.054

At specific days after sowing, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

Table 51a: Effect of nitrogen on plant height, dry weights and leaf area of wheat at physiological maturity stage (2014-15)

Nitrogen	Plant height(cm)	Leaf dry weight plant ⁻¹ (g)	Stem dry weight plant ⁻¹ (g)	Spike dry weight plant ⁻¹ (g)	Total dry weight plant ⁻¹ (g)	Leaf area plant ⁻¹ (cm ²)
N ₀	82.406 b	1.322 c	4.020 b	1.889 c	7.230 c	164.625 c
N ₁	94.369 a	1.788 b	4.322 a	4.293 b	10.403 b	199.703 ab
N ₂	98.689 a	1.953 a	4.509 a	4.802 a	11.264 a	209.706 a
N ₃	96.469 a	1.750 b	4.403 a	4.418 b	10.571 ab	198.131 b
CV (%)	3.585	8.921	3.893	3.269	2.033	11.996

At specific days after sowing, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

Table 51b: Effect of nitrogen on plant height, dry weights and leaf area of wheat at physiological maturity stage (2015-16)

Nitrogen	Plant height(cm)	Leaf dry weight plant ⁻¹ (g)	Stem dry weight plant ⁻¹ (g)	Spike dry weight plant ⁻¹ (g)	Total dry weight plant ⁻¹ (g)	Leaf area plant ⁻¹ (cm ²)
N ₀	83.733 b	1.345 c	4.158 b	1.837 c	7.340 c	167.311 c
N ₁	95.888 a	1.819 b	4.472 a	4.270 b	10.560 b	202.988 ab
N ₂	100.276 a	1.987 a	4.662 a	4.784 a	11.434 a	213.129 a
N ₃	98.021 a	1.780 b	4.554 a	4.396 b	10.731 b	201.375 b
CV (%)	3.587	8.918	3.830	3.294	2.035	12.054

At specific days after sowing, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

Table 52a: Interaction effect of irrigation and nitrogen on plant height, dry weights and leaf area of wheat at physiological maturity stage (2014-15)

Interaction (Irrigation × Nitrogen)	Plant height (cm)	Leaf dry weight plant ⁻¹ (g)	Stem dry weight plant ⁻¹ (g)	Spike dry weight plant ⁻¹ (g)	Total dry weight plant ⁻¹ (g)	Leaf area plant ⁻¹ (cm ²)
I ₀ N ₀	76.545 m	1.105 k	3.542 i	1.843 o	6.491 k	148.137 h
I ₀ N ₁	86.981 j	1.528 h	3.847 h	3.722 l	9.097 g	198.010 b-e
I ₀ N ₂	90.357 h	1.724 g	3.919 gh	4.079 j	9.722 f	203.117 b-d
I ₀ N ₃	88.896 i	1.514 hi	3.955 g	3.799 k	9.267 g	193.065 b-e
I ₁ N ₀	79.707 l	1.251 j	3.870 gh	1.848 n	6.969 j	160.910 gh
I ₁ N ₁	90.718 h	1.786 e-g	4.201 ef	4.125 i	10.113 e	191.581 c-e
I ₁ N ₂	94.889 f	1.927 cd	4.241 ef	4.623 e	10.791 d	195.361 b-e
I ₁ N ₃	92.722 g	1.734 fg	4.151 f	4.403 h	10.288 e	186.295 d-f
I ₂ N ₀	84.939 k	1.417 i	4.264 e	1.596 p	7.277 i	169.975 fg
I ₂ N ₁	97.552 e	1.872 c-e	4.428 d	4.579 f	10.879 d	201.926 b-d
I ₂ N ₂	102.356 c	2.034 ab	4.887 b	4.977 c	11.898 b	212.102 ab
I ₂ N ₃	99.738 d	1.831 d-f	4.638 c	4.471 g	10.940 d	201.541 b-d
I ₃ N ₀	88.434 i	1.515 hi	4.402 d	2.267 m	8.184 h	179.479 e-g
I ₃ N ₁	102.226 c	1.966 bc	4.811 b	4.748 d	11.525 c	207.295 bc
I ₃ N ₂	107.154 a	2.128 a	4.988 a	5.529 a	12.645 a	228.244 a
I ₃ N ₃	104.519 b	1.919 cd	4.870 b	5.000 b	11.789 b	211.622 a-c
CV (%)	3.585	8.921	3.893	3.269	2.033	11.996

At specific days after sowing, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

Table 52b: Interaction effect of irrigation and nitrogen on plant height, dry weights and leaf area of wheat at physiological maturity stage (2015-16)

Interaction (Irrigation × Nitrogen)	Plant height (cm)	Leaf dry weight plant ⁻¹ (g)	Stem dry weight plant ⁻¹ (g)	Spike dry weight plant ⁻¹ (g)	Total dry weight plant ⁻¹ (g)	Leaf area plant ⁻¹ (cm ²)
I ₀ N ₀	78.008 m	1.125 j	3.685 i	1.803 o	6.613 k	150.988 h
I ₀ N ₁	88.643 j	1.555 g	3.999 h	3.714 l	9.268 g	201.821 b-d
I ₀ N ₂	92.084 h	1.754 f	4.074 gh	4.076 j	9.904 f	207.025 b-d
I ₀ N ₃	90.595 i	1.541 gh	4.109 g	3.792 k	9.441 g	196.780 b-e
I ₁ N ₀	81.029 l	1.273 i	3.986 h	1.815 n	7.075 j	163.956 gh
I ₁ N ₁	92.222 h	1.818 ef	4.328 ef	4.119 i	10.266 e	195.208 c-e
I ₁ N ₂	96.462 f	1.961 b-d	4.372 ef	4.622 e	10.955 d	199.060 b-e
I ₁ N ₃	94.259 g	1.765 f	4.279 f	4.399 h	10.443 e	189.822 d-f
I ₂ N ₀	86.173 k	1.441 h	4.412 e	1.526 p	7.379 i	173.207 fg
I ₂ N ₁	98.969 e	1.903 c-e	4.588 d	4.539 f	11.030 d	205.766 b-d
I ₂ N ₂	103.843 c	2.068 ab	5.051 b	4.944 c	12.063 b	216.135 ab
I ₂ N ₃	101.187 d	1.861 d-f	4.798 c	4.432 g	11.092 d	205.373 b-d
I ₃ N ₀	89.723 ij	1.542 gh	4.550 d	2.201 m	8.294 h	181.091 e-g
I ₃ N ₁	103.716 c	2.000 bc	4.972 b	4.705 d	11.678 c	209.157 b-d
I ₃ N ₂	108.717 a	2.166 a	5.153 a	5.495 a	12.814 a	230.294 a
I ₃ N ₃	106.043 b	1.953 cd	5.031 b	4.961 b	11.946 b	213.523 a-c
CV (%)	3.587	8.918	3.830	3.294	2.035	12.054

At specific days after sowing, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

4.4. Water Relations

4.4.1. Moisture retention capacity (MRC)

Irrigation levels had significant effects on moisture retention capacity (MRC) at all the time of the day in both the years and are presented in Table 53a for first year (2014-15) and in Table 53b for second year (2015-16). Higher MRC values were found at the initial stages or early hours of the day in both the growing seasons but MRC decreased gradually at the later part of the day. This might be due to increased dryness and also because of higher transpiration rates. The highest MRC was obtained in three irrigations (I_3) followed by two irrigations (I_2) and the lowest value were found in rain-fed (I_0) condition at all the time of the day in both the years. The irrigated plants had higher moisture retention capacity (MRC) than the rain-fed crops. This result was in agreement with Bahadur (2008) in barley. Sarker *et al.* (1999) also found higher moisture retention capacity (MRC) in Opata under irrigated condition. Similar results were also found by Haider (2002) in different wheat varieties grown under various soil moisture regimes. The ability of a leaf to retain higher moisture may be due to its higher sensitivity of stomatal opening with higher leaf area.

Moisture retention capacity (MRC) did not differ significantly due to varieties at all the time of the day in both the years and are given in Table 54a for first year (2014-15) and in Table 54b for second year (2015-16). Higher moisture retention capacity (MRC) values were found in BARI Gom 24 (V_1) than BARI Gom 26 (V_2).

Moisture retention capacity (MRC) was significantly influenced by split applications of nitrogen at all the time of the day in both the years and is presented in Table 55a for first year (2014-15) and Table 55b for second year (2015-16). Flag leaf in both the two wheat varieties exhibited maximum MRC at 8:30 am and thereafter decreased gradually at the later part of the day. The highest MRC was found in four splits (N_3) application of nitrogen which was statistically identical with three split (N_2) and basal (N_1) applications of nitrogen and the lowest value was observed in control (N_0) at all the time of the day in both the years.

Different treatment combinations of irrigation and nitrogen had significant influence on moisture retention capacity (MRC) at all the time of the day in both the years and are presented in Table 56a for first year (2014-15) and in Table 56b for second year (2015-16). The highest MRC was observed in the treatment combination of three irrigations (I_3) $\times$ four split (N_3) applications of nitrogen which was significantly differed from the remaining treatment combinations and the lowest value was found in rain-fed (I_0) $\times$ control (N_0) at all the time of the day in both the years.

Table 53a: Effect of irrigation on moisture retention capacity (%) of wheat (2014-15)

Irrigation	Time of the day											
	8:30	9:00	9:30	10:00	10:30	11:00	11:30	12:00	12:30	2:00	3:30	5:00
I ₀	73.343 d	71.197 d	69.606 d	68.422 d	67.457 d	66.435 d	65.391 d	64.239 d	63.086 d	59.959 d	56.765 d	52.659 d
I ₁	75.887 c	73.700 c	72.029 c	70.855 c	69.813 c	68.767 c	67.750 c	66.565 c	65.395 c	62.265 c	59.125 c	54.975 c
I ₂	77.339 b	75.193 b	73.638 b	72.478 b	71.474 b	70.450 b	69.396 b	68.234 b	67.068 b	63.939 b	60.790 b	56.629 b
I ₃	79.507 a	77.329 a	75.611 a	74.438 a	73.404 a	72.347 a	71.278 a	70.123 a	68.981 a	65.846 a	62.665 a	58.553 a
CV (%)	4.366	4.941	5.439	5.515	5.645	5.817	5.727	5.728	5.905	6.361	6.700	6.611

In a column, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

Table 53b: Effect of irrigation on moisture retention capacity (%) of wheat (2015-16)

Irrigation	Time of the day											
	8:30	9:00	9:30	10:00	10:30	11:00	11:30	12:00	12:30	2:00	3:30	5:00
I ₀	73.965 d	71.827 d	70.214 d	69.026 d	68.052 d	67.017 d	65.966 d	64.812 d	63.643 d	60.476 d	57.244 d	53.101 d
I ₁	76.550 c	74.350 c	72.658 c	71.450 c	70.422 c	69.367 c	68.346 c	67.158 c	65.972 c	62.801 c	59.624 c	55.436 c
I ₂	78.029 b	75.841 b	74.266 b	73.095 b	72.092 b	71.059 b	70.006 b	68.842 b	67.660 b	64.489 b	61.303 b	57.104 b
I ₃	80.174 a	77.899 a	76.257 a	75.062 a	74.020 a	72.971 a	71.905 a	70.749 a	69.589 a	66.413 a	63.194 a	59.045 a
CV (%)	4.366	4.42	5.439	5.516	5.645	5.818	5.727	5.782	5.905	6.361	6.700	6.611

In a column, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

Table 54a: Effect of variety on moisture retention capacity (%) of wheat (2014-15)

Variety	Time of the day											
	8:30	9:00	9:30	10:00	10:30	11:00	11:30	12:00	12:30	2:00	3:30	5:00
V ₁	76.548 a	74.394 a	72.761 a	71.553 a	70.576 a	69.537 a	68.486 a	67.325 a	66.165 a	63.040 a	59.877 a	55.772 a
V ₂	76.489 a	74.315 a	72.681 a	71.543 a	70.498 a	69.463 a	68.421 a	67.255 a	66.100 a	62.964 a	59.795 a	55.636 a
CV (%)	4.366	4.941	5.439	5.515	5.645	5.817	5.727	5.728	5.905	6.361	6.700	6.611

In a column, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

Table 54b: Effect of variety on moisture retention capacity (%) of wheat (2015-16)

Variety	Time of the day											
	8:30	9:00	9:30	10:00	10:30	11:00	11:30	12:00	12:30	2:00	3:30	5:00
V ₁	77.209 a	75.019 a	73.389 a	72.163 a	71.187 a	70.141 a	69.089 a	67.926 a	66.749 a	63.583 a	60.383 a	56.240 a
V ₂	77.150 a	74.940 a	73.309 a	72.153 a	71.107 a	70.066 a	69.023 a	67.855 a	66.683 a	63.507 a	60.300 a	56.103 a
CV (%)	4.366	4.42	5.439	5.516	5.645	5.818	5.727	5.782	5.905	6.361	6.700	6.611

In a column, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

Table 55a: Effect of nitrogen on moisture retention capacity (%) of wheat (2014-15)

Nitrogen	Time of the day											
	8:30	9:00	9:30	10:00	10:30	11:00	11:30	12:00	12:30	2:00	3:30	5:00
N ₀	75.005 b	72.797 b	71.192 b	70.025 b	69.083 b	68.048 b	67.012 b	65.850 b	64.713 b	61.576 b	58.396 b	54.323 b
N ₁	76.305 ab	74.190 ab	72.539 ab	71.336 ab	70.307 ab	69.278 ab	68.214 ab	67.068 ab	65.937 ab	62.819 ab	59.687 ab	55.540 ab
N ₂	77.008 a	74.789 a	73.170 a	72.007 a	70.973 a	69.930 a	68.888 a	67.724 a	66.509 a	63.383 a	60.201 a	56.040 a
N ₃	77.757 a	75.642 a	73.983 a	72.827 a	71.786 a	70.743 a	69.700 a	68.519 a	67.373 a	64.230 a	61.060 a	56.913 a
CV (%)	4.366	4.941	5.439	5.515	5.645	5.817	5.727	5.728	5.905	6.361	6.700	6.611

In a column, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

Table 55b: Effect of nitrogen on moisture retention capacity (%) of wheat (2015)

Nitrogen	Time of the day											
	8:30	9:00	9:30	10:00	10:30	11:00	11:30	12:00	12:30	2:00	3:30	5:00
N ₀	75.653 b	73.409 b	71.807 b	70.622 b	69.680 b	68.639 b	67.601 b	66.437 b	65.283 b	62.107 b	58.889 b	54.779 b
N ₁	76.964 ab	74.814 ab	73.166 ab	71.944 ab	70.914 ab	69.880 ab	68.814 ab	67.666 ab	66.518 ab	63.360 ab	60.191 ab	56.006 ab
N ₂	77.672 a	75.417 a	73.802 a	72.621 a	71.587 a	70.538 a	69.494 a	68.328 a	67.095 a	63.929 a	60.709 a	56.510 ab
N ₃	78.429 a	76.277 a	74.621 a	73.447 a	72.406 a	71.358 a	70.313 a	69.130 a	67.967 a	64.784 a	61.576 a	57.390 a
CV (%)	4.366	4.42	5.439	5.516	5.645	5.818	5.727	5.782	5.905	6.361	6.700	6.611

In a column, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

Table 56a: Interaction effect of irrigation and nitrogen on moisture retention capacity (%) of wheat (2014-15)

Interaction (Irrigation × Nitrogen)	Time of the day											
	8:30	9:00	9:30	10:00	10:30	11:00	11:30	12:00	12:30	2:00	3:30	5:00
I ₀ N ₀	72.331 i	70.135 h	68.513 j	67.331 j	66.538 i	65.525 j	64.494 j	63.365 j	62.207 j	59.066 j	55.873 h	51.847 i
I ₀ N ₁	73.085 i	70.985 gh	69.408 ij	68.229 ij	67.201 hi	66.195 ij	65.162 ij	64.024 ij	62.853 ij	59.737 ij	56.567 gh	52.454 hi
I ₀ N ₂	74.000 h	71.759 fg	70.195 hi	69.003 hi	67.984 gh	66.928 hi	65.870 hi	64.692 hi	63.559 hi	60.434 hi	57.246 fg	53.103 gh
I ₀ N ₃	73.954 h	71.908 fg	70.309 hi	69.126 hi	68.107 gh	67.091 hi	66.037 hi	64.877 hi	63.727 hi	60.600 hi	57.375 fg	53.234 gh
I ₁ N ₀	75.052 g	72.710 f	71.066 gh	69.883 gh	68.836 fg	67.787 gh	66.795 gh	65.612 gh	64.496 gh	61.346 gh	58.136 f	54.025 g
I ₁ N ₁	75.834 fg	73.781 e	72.079 fg	70.902 fg	69.880 ef	68.826 fg	67.783 fg	66.612 fg	65.492 fg	62.359 fg	59.330 de	55.169 f
I ₁ N ₂	76.061 ef	73.926 e	72.256 ef	71.080 ef	70.050 e	69.015 ef	68.001 ef	66.829 ef	65.525 fg	62.412 f	59.242 e	55.059 f
I ₁ N ₃	76.603 ef	74.382 e	72.715 ef	71.555 ef	70.484 e	69.440 ef	68.421 ef	67.205 ef	66.069 ef	62.943 ef	59.793 de	55.647 ef
I ₂ N ₀	75.867 fg	73.865 e	72.280 ef	71.100 ef	70.222 e	69.164 ef	68.107 ef	66.954 ef	65.839 ef	62.723 ef	59.536 de	55.378 ef
I ₂ N ₁	76.876 e	74.598 e	73.136 de	71.981 de	70.925 de	69.951 de	68.860 de	67.712 de	66.607 de	63.505 de	60.345 cd	56.183 de
I ₂ N ₂	77.856 d	75.573 d	73.999 d	72.844 d	71.790 d	70.752 d	69.707 d	68.556 d	67.256 d	64.122 d	60.954 c	56.810 d
I ₂ N ₃	78.756 c	76.736 c	75.138 c	73.988 c	72.958 c	71.934 c	70.910 c	69.713 c	68.571 c	65.404 c	62.324 b	58.145 c
I ₃ N ₀	76.772 e	74.478 e	72.912 ef	71.783 ef	70.736 e	69.715 d-f	68.652 ef	67.470 ef	66.310 d-f	63.170 d-f	60.039 c-e	56.042 d-e
I ₃ N ₁	79.425 bc	77.397 bc	75.535 bc	74.231 bc	73.221 bc	72.141 bc	71.051 bc	69.923 bc	68.794 bc	65.676 bc	62.506 b	58.356 bc
I ₃ N ₂	80.112 b	77.896 b	76.229 b	75.100 b	74.068 b	73.025 b	71.976 b	70.818 b	69.696 b	66.563 b	63.362 b	59.190 b
I ₃ N ₃	81.716 a	79.543 a	77.770 a	76.637 a	75.593 a	74.509 a	73.431 a	72.282 a	71.123 a	67.974 a	64.751 a	60.625 a
CV (%)	4.366	4.941	5.439	5.515	5.645	5.817	5.727	5.728	5.905	6.361	6.700	6.611

In a column, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

Table 56b: Interaction effect of irrigation and nitrogen on moisture retention capacity (%) of wheat (2015-16)

Interaction (Irrigation × Nitrogen)	Time of the day											
	8:30	9:00	9:30	10:00	10:30	11:00	11:30	12:00	12:30	2:00	3:30	5:00
I ₀ N ₀	72.944 j	70.755 h	69.111 j	67.925 j	67.125 i	66.099 j	65.061 j	63.930 j	62.755 j	59.574 j	56.344 h	52.282 i
I ₀ N ₁	73.704 j	71.613 gh	70.014 ij	68.830 ij	67.793 hi	66.775 ij	65.735 ij	64.595 ij	63.407 ij	60.251 ij	57.045 gh	52.894 hi
I ₀ N ₂	74.628 i	72.394 fg	70.808 hi	69.611 hi	68.583 gh	67.514 hi	66.449 hi	65.269 hi	64.119 hi	60.954 hi	57.729 fg	53.548 gh
I ₀ N ₃	74.582 i	72.544 fg	70.923 hi	69.736 hi	68.707 gh	67.679 hi	66.618 hi	65.456 hi	64.289 hi	61.122 hi	57.859 fg	53.680 gh
I ₁ N ₀	75.706 h	73.352 f	71.686 gh	70.470 gh	69.437 fg	68.379 gh	67.382 gh	66.197 gh	65.065 gh	61.875 gh	58.627 f	54.478 g
I ₁ N ₁	76.496 gh	74.432 e	72.708 fg	71.498 fg	70.490 ef	69.426 fg	68.380 fg	67.206 fg	66.070 fg	62.896 fg	59.831 de	55.631 f
I ₁ N ₂	76.725 e-g	74.579 e	72.887 ef	71.677 ef	70.662 e	69.617 ef	68.600 ef	67.425 ef	66.103 fg	62.950 f	59.742 e	55.521 f
I ₁ N ₃	77.271 e-g	75.039 e	73.350 ef	72.156 ef	71.100 e	70.045 ef	69.023 ef	67.804 ef	66.651 ef	63.485 ef	60.297 de	56.114 ef
I ₂ N ₀	76.544 f-h	74.502 e	72.896 ef	71.706 ef	70.829 e	69.762 ef	68.706 ef	67.551 ef	66.419 ef	63.264 ef	60.038 de	55.842 ef
I ₂ N ₁	77.562 e	75.241 e	73.760 de	72.593 de	71.539 de	70.556 de	69.466 de	68.316 de	67.195 de	64.052 de	60.855 cd	56.655 de
I ₂ N ₂	78.551 d	76.225 d	74.631 d	73.464 d	72.411 d	71.364 d	70.320 d	69.168 d	67.849 d	64.674 d	61.468 c	57.286 d
I ₂ N ₃	79.459 c	77.397 c	75.779 c	74.618 c	73.589 c	72.555 c	71.534 c	70.335 c	69.176 c	65.968 c	62.850 b	58.633 c
I ₃ N ₀	77.416 ef	75.028 e	73.535 ef	72.385 ef	71.329 e	70.316 d-f	69.256 ef	68.071 ef	66.895 d-f	63.714 d-f	60.546 c-e	56.513 d-f
I ₃ N ₁	80.091 bc	77.967 bc	76.180 bc	74.854 bc	73.835 bc	72.763 bc	71.676 bc	70.547 bc	69.400 bc	66.242 bc	63.034 b	58.845 bc
I ₃ N ₂	80.785 b	78.471 b	76.881 b	75.730 b	74.689 b	73.654 b	72.609 b	71.450 b	70.311 b	67.137 b	63.897 b	59.687 b
I ₃ N ₃	82.402 a	80.129 a	78.434 a	77.280 a	76.228 a	75.151 a	74.077 a	72.927 a	71.750 a	68.559 a	65.298 a	61.134 a
CV (%)	4.366	4.42	5.439	5.516	5.645	5.818	5.727	5.782	5.905	6.361	6.700	6.611

In a column, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

4.4.2. Relative leaf water content (RLWC)

The relative leaf water content was studied at anthesis stage under different irrigation levels are given in Table 57a for first year (2014-15) and in Table 57b for second year (2015-16). Irrigation levels showed significant effect on relative leaf water content (RLWC) at every occasion of the day in both the years. The highest RLWC was observed in three irrigations (I_3) at every occasion of the day in both the years. The results were statistically identical to two irrigations (I_2) for 8:00 am in both the years. The lowest RLWC was found in rain-fed (I_0) condition in both the years. The irrigated plants of both the varieties at different times of the day always had higher RLWC than the rain-fed plants in both the years. This result was in agreement with Rajagopal *et al.* (1977), Nayak *et al.* (1983), Rahman (1993), Sairam (1993), Haider (1997), Sarker *et al.* (1999), Paul *et al.* (2002), Haider and Paul (2003) and Rahman (2004) in wheat. The relative leaf water content (RLWC) controls the leaf tissue turgor pressure which ultimately maintains the activities of leaf resulting to high rate of photosynthesis (Thomas *et al.*, 2005). Kramer (1969) expressed that higher RLWC was associated with higher TDM rates of the irrigated plants because of the importance of cell turgidity in relation to the opening and closing of stomata, expansion of leaves and flowers, and movement of water and nutrients to various parts of the plants. The highest relative leaf water content (RLWC) of all irrigation treatments were observed at 8:30 am in both the years. Rahman and Paul (1998) were also found that the highest relative leaf water content (RLWC) in wheat leaves at 8:30 am. RLWC of both the varieties was higher in the morning, fell during noon, showing some recovery in the afternoon and this result was in agreement with Begum and Paul (1993), Rahman (1993), Sarker *et al.* (1999), Paul *et al.* (2002) and Haider (2002). The steady decline of RLWC at the midday might be due to higher evapotranspiration owing to increased temperature and light intensity. Agenbag (1995) opined that rain-fed condition decreased RLWC as well as increased leaf diffusive resistance. Chandrasekar *et al.* (2000) also reported that rain-fed condition caused decline in relative water content in both the tetraploid and hexaploid wheat. I_3 treatment had the highest RLWC as irrigation level increased RLWC. Similar results were reported by Begum and Paul (1993) in mustard, Rahman and Paul (1998) and Haider and Paul (2003) in wheat.

Relative leaf water content (RLWC) did not vary significantly due to varieties at every occasion of the day in both the years and are presented in Table 58a for first year (2014-15) and in Table 58b for second year (2015-16). Between the two varieties, higher RLWC was

observed in BARI Gom 26 at 8:30 am and 12:00 noon but at 4:30 pm higher RLWC was found in BARI Gom 24 in both the years.

Relative leaf water content (RLWC) varied significantly due to split applications of nitrogen at every occasion of the day in both the growing seasons and are presented in Table 59a for first year (2014-15) and in Table 59b for second year (2015-16). It was observed that the highest RLWC was at 8:00 am but at midday that is, at 12:00 noon it decreased, while it increased gradually at the later part of the day at 4:30 pm. The highest RLWC was recorded in three splits (N_2) application of nitrogen at every occasion of the day in both the years. That was statistically identical to basal (N_1) and four split (N_3) applications of nitrogen for 8:00 am and four split (N_3) applications of nitrogen for 12:00 noon and 4:30 pm in both the years. The lowest values were found in control (N_0) at every occasion of the day in both the growing seasons. This result was in agreement with Rahman (2004) in wheat.

Relative leaf water content (RLWC) at every occasion of the day varied significantly due to the interaction of irrigation and nitrogen in both the years and are presented in Table 60a for first year (2014-15) and Table 60b for second year (2015-16). The highest RLWC at every occasion of the day was recorded in the treatment combination of three irrigations (I_3) $\times$ three split (N_2) applications of nitrogen in both the years. The lowest RLWC was found in rain-fed (I_0) $\times$ control (N_0) in both the growing seasons.

Table 57a: Effect of irrigation on relative leaf water content (%) of wheat (2014-15)

Irrigation	8:00 am	12:00 noon	4:30 pm
I ₀	81.463 b	63.276 d	74.500 c
I ₁	82.419 b	64.266 c	75.386 bc
I ₂	84.674 a	65.533 b	76.546 b
I ₃	85.891 a	66.677 a	78.065 a
CV (%)	3.044	2.785	1.062

In a column, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

Table 57b: Effect of irrigation on relative leaf water content (%) of wheat (2015-16)

Irrigation	8:00 am	12:00 noon	4:30 pm
I ₀	81.990 b	63.685 d	75.048 c
I ₁	82.942 b	64.674 c	75.948 bc
I ₂	85.235 a	65.978 b	77.125 b
I ₃	86.446 a	67.102 a	78.658 a
CV (%)	3.044	2.785	1.064

In a column, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

Table 58a: Effect of variety on relative leaf water content (%) of wheat (2014-15)

Variety	8:00 am	12:00 noon	4:30 pm
V ₁	83.604 a	64.912 a	76.164 a
V ₂	83.619 a	64.963 a	76.084 a
CV (%)	3.044	2.785	1.062

In a column, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

Table 58b: Effect of variety on relative leaf water content (%) of wheat (2015-16)

Variety	8:00 am	12:00 noon	4:30 pm
V ₁	84.146 a	65.334 a	76.735 a
V ₂	84.161 a	65.386 a	76.655 a
CV (%)	3.044	2.785	1.064

In a column, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

Table 59a: Effect of nitrogen on relative leaf water content (%) of wheat (2014-15)

Nitrogen	8:00 am	12:00 noon	4:30 pm
N ₀	81.010 b	63.519 c	73.925 c
N ₁	83.736 a	64.666 b	75.904 b
N ₂	85.107 a	66.160 a	77.543 a
N ₃	84.594 a	65.406 ab	77.125 a
CV (%)	3.044	2.785	1.062

In a column, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

Table 59b: Effect of nitrogen on relative leaf water content (%) of wheat (2015-16)

Nitrogen	8:00 am	12:00 noon	4:30 pm
N ₀	81.535 b	63.931 c	74.479 c
N ₁	84.278 a	65.086 b	76.473 b
N ₂	85.658 a	66.590 a	78.124 a
N ₃	85.142 a	65.831 ab	77.703 a
CV (%)	3.044	2.785	1.064

In a column, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

Table 60a: Interaction effect of irrigation and nitrogen on relative leaf water content (%) of wheat (2014-15)

Interaction (Irrigation × Nitrogen)	8:00 am	12:00 noon	4:30pm
I ₀ N ₀	79.389 h	61.622 j	72.434 i
I ₀ N ₁	81.525 g	62.812 i	74.565 f-h
I ₀ N ₂	82.721 ef	64.639 fg	75.669 ef
I ₀ N ₃	82.216 fg	64.030 h	75.331 e-g
I ₁ N ₀	79.857 h	62.884 i	73.479 hi
I ₁ N ₁	82.299 fg	63.916 h	75.258 e-g
I ₁ N ₂	83.963 d	65.444 cd	76.497 de
I ₁ N ₃	83.555 d	64.821 e-g	76.308 de
I ₂ N ₀	81.598 g	64.395 gh	74.248 gh
I ₂ N ₁	84.791 c	65.256 de	76.309 de
I ₂ N ₂	86.272 b	66.541 b	78.188 bc
I ₂ N ₃	86.034 b	65.938 c	77.439 cd
I ₃ N ₀	83.197 de	65.174 d-f	75.539 e-g
I ₃ N ₁	86.329 b	66.681 b	77.482 cd
I ₃ N ₂	87.472 a	68.016 a	79.818 a
I ₃ N ₃	86.569 b	66.837 b	79.421 ab
CV (%)	3.044	2.785	1.062

In a column, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

Table 60b: Interaction effect of irrigation and nitrogen on relative leaf water content (%) of wheat (2015-16)

Interaction (Irrigation $\times$ Nitrogen)	8:00 am	12:00 noon	4:30pm
I ₀ N ₀	79.903 h	62.020 j	72.967 i
I ₀ N ₁	82.052 g	63.218 i	75.115 f-h
I ₀ N ₂	83.256 ef	65.058 fg	76.226 ef
I ₀ N ₃	82.748 fg	64.444 h	75.886 e-g
I ₁ N ₀	80.364 h	63.284 i	74.028 hi
I ₁ N ₁	82.822 fg	64.322 h	75.820 e-g
I ₁ N ₂	84.496 d	65.860 cd	77.068 de
I ₁ N ₃	84.086 d	65.232 e-g	76.878 de
I ₂ N ₀	82.138 g	64.832 gh	74.809 gh
I ₂ N ₁	85.353 c	65.700 de	76.886 de
I ₂ N ₂	86.843 b	66.993 b	78.780 bc
I ₂ N ₃	86.604 b	66.387 c	78.025 cd
I ₃ N ₀	83.734 de	65.589 d-f	76.113 e-g
I ₃ N ₁	86.887 b	67.106 b	78.071 cd
I ₃ N ₂	88.037 a	68.450 a	80.424 a
I ₃ N ₃	87.128 b	67.263 b	80.024 ab
CV (%)	3.044	2.785	1.064

In a column, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

4.5. Biochemical Characteristics

4.5.1. Estimation of chlorophyll

The effect of irrigation treatments on chlorophyll a, chlorophyll b, total chlorophyll content and chlorophyll a : b in both the years and are presented in Table 61a for first year (2014-15) and in Table 61b for second year (2015-16). High chlorophyll contents might contribute to higher photosynthetic rate and significant positive correlation between chlorophyll content and photosynthesis rate (Thomas *et al.*, 2005). Irrigation treatments showed significant effects on chlorophyll a, chlorophyll b, total chlorophyll content and chlorophyll a : b in both the years. Irrigated plants had higher chlorophyll a, chlorophyll b and total chlorophyll than the rain-fed plants in flag leaf. Three irrigated (I_3) plants contained the highest chlorophyll a, chlorophyll b and total chlorophyll which was statistically similar with two (I_2) and followed by one (I_1) irrigated plants in both the years. Rain-fed condition reduced chlorophyll a, chlorophyll b and total chlorophyll in flag leaf. Similar result was reported by Sarker *et al.* (1999), Chandrasekar *et al.* (2000), Nyachiro *et al.* (2001), Haider (2002), Haider and Paul (2003), Mollah (2007) and Abdelraouf *et al.* (2013). Paul *et al.* (2002) also showed that irrigated plants had higher chlorophyll content than rain-fed plants in wheat. Silaeva and Tkachuk (1982) reported that chloroplasts, photosynthetic membranes and the amount of thylaloid grana decreased with the intensification of soil water stress. The highest chlorophyll a : b was recorded in one irrigated (I_1) plant which was statistically at par with two irrigations (I_2) and rain-fed condition in both the years. This result was in agreement with Ashraf *et al.* (2001) in pearl millet, where they observed no significant effect on chlorophyll a : b ratio but a slight increase was observed under water deficit condition. Ashraf *et al.* (1994) noticed that chlorophyll a : b increased under rain-fed conditions and the effect was more pronounced in the drought susceptible varieties. Abdrakhimov *et al.* (1996) reported that total chlorophyll and chlorophyll a : b ratio in wheat leaves were not affected by water shortage.

Chlorophyll content did not varied significantly due to variety in both the years are shown in Table 62a for first year (2014-15) and Table 62b for second year (2015-16). But varieties had significant effect on chlorophyll a : b ratio. The highest chlorophyll a : b ratio was recorded in BARI Gom 24 in both the years.

Chlorophyll a, chlorophyll b, total chlorophyll and chlorophyll a : b ratios were significantly influenced by split applications of nitrogen in both the years and are given in Table 63a for first year (2014-15) and in Table 63b for second year (2015-16). The highest chlorophyll a,

chlorophyll b and total chlorophyll content were recorded in four split (N_3) applications of nitrogen which was statistically at par with three split (N_2) applications of nitrogen in both the years. The highest chlorophyll a : b was recorded in basal (N_1) application of nitrogen which was statistically similar with three split (N_2) application of nitrogen and control (N_0). The lowest Chlorophyll a, chlorophyll b and total chlorophyll were found in control (N_0) plant in both the years. Very close link between total chlorophyll and nitrogen content was observed and many investigators proved that (Amaliotis *et al.*, 2004, Khursheed and Mahammad 2015). It is understandable, because nitrogen is a structural element of chlorophyll and protein molecules, and thereby affects formation of chloroplasts and accumulation of chlorophyll in them (Tucker, 2004). Chlorophyll content is approximately proportional to leaf nitrogen content, too (Bojovic and Markovic, 2009). Abdelraouf *et al.* (2013) reported that nitrogen fertilizer levels significantly affected chlorophyll content in wheat. Decreasing level of fertilizer significantly decreased chlorophyll content.

The interaction effects of irrigation level and splits application of nitrogen were significant for chlorophyll a, chlorophyll b and total chlorophyll content in both the years and are shown in Table 64a for first year (2014-15) and in Table 64b for second year (2015-16). The three irrigated (I_3) plants with four splits (N_3) application of nitrogen contained the highest amount of chlorophyll a, chlorophyll b and total chlorophyll. The lowest amounts of chlorophyll a, chlorophyll b and total chlorophyll were observed in rain-fed (I_0) condition $\times$ control (N_0) plant in both the years.

4.5.2. Proline accumulation

Irrigation levels showed significant effect on proline accumulation in both the years and are presented in Table 61a for first year (2014-15) and Table 61b for second year (2015-16). Proline accumulation decreased with increasing irrigation frequencies. Significantly the highest amount of proline was observed in the rain-fed (I_0) plants which can be related to water stress at flag leaf stage followed by one (I_1) and two (I_2) irrigated plants. These results were as par with the findings of Haider and Paul (2003) and Chandra *et al.* (2004) who reported that water stress increased proline accumulation in wheat. Mostajeran and Eichi (2009) stated that drought / stress have significant correlation with solute accumulation like proline and varieties which accumulate high proline need to be considered in future context of climate variability. The least amount of proline was accumulated in the three irrigated (I_3) plants in both the years. Irrigation regimes had significant effect on proline accumulation in flag leaf of both the varieties for both the years and significant increases in proline

accumulation were noticed due to limited water supply in the present investigation. Lower proline content in the irrigated plants was noticed in both the varieties and it might be due to the oxidation of proline in the irrigated condition as free proline converted to glutamic acid and other compounds under non-stress condition. Paul *et al.* (2002) also noticed lower proline content in the irrigated wheat plants. Similar results were also reported by Al-Tabbal *et al.* (2005) and Ashraf *et al.* (1994) in wheat and Bahadur (2008) in barley. Singh and Patel (1996) reported that water stress at any growth stage in wheat increased respiration rate as well as proline accumulation. Accumulation proline could also serve as a readily available energy and nitrogen source for use upon the relief of stress (Blum and Eborcon 1976). Accumulation proline can also be use as a source of energy (Stewart 1972).

Proline accumulation did not differ significantly due to variety in both the years are shown in Table 62a for first year (2014-15) and in Table 62b for second year (2015-16). Between the two varieties, some higher amount of proline content was observed in BARI Gom 26 (V₂).

Nitrogen treatments had significant effect on proline accumulation in both the growing seasons and are presented in Table 63a for first year (2014-15) and in Table 63b for second year (2015-16). Significantly the highest amount of proline was accumulated in control (N₀) plants which were statistically similar with basal (N₁) and followed by three split (N₂) applications of nitrogen in both the years. The lowest amount of proline was accumulated in four split (N₃) applications of nitrogen plants in both the years.

Proline accumulation varied significantly due to the interaction of irrigation and nitrogen in both the years and is given in Table 64a for first year (2014-15) and in Table 64b for second year (2015-16). Rain-fed (I₀) with control (N₀) plants accumulated the highest amount of proline than the other treatment combinations in both the years which was statistically identical to rain-fed (I₀) with basal (N₁) application of nitrogen plants. The lowest amount of proline accumulation was noticed in three irrigations (I₃) × four split (N₃) applications of nitrogen plants in both the years.

Table 61a: Effect of irrigation on Chlorophyll and Proline content of wheat (2014-15)

Irrigation	Chlorophyll a (mg g ⁻¹)	Chlorophyll b (mg g ⁻¹)	Chlorophyll a+b (mg g ⁻¹)	Chlorophyll a:b	Proline accumulation (µg g ⁻¹ fresh wt.)
I ₀	1.987 c	0.702 c	2.689 c	2.831 ab	190.542 a
I ₁	2.260 bc	0.794 bc	3.033 bc	2.859 a	178.927 b
I ₂	2.439 ab	0.867 ab	3.307 ab	2.811 ab	144.209 c
I ₃	2.588 a	0.994 a	3.509 a	2.709 b	125.143 d
CV (%)	2.071	12.558	2.578	5.365	6.597

In a column, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

Table 61b: Effect of irrigation on Chlorophyll and Proline content of wheat (2015-16)

Irrigation	Chlorophyll a (mg g ⁻¹)	Chlorophyll b (mg g ⁻¹)	Chlorophyll a+b (mg g ⁻¹)	Chlorophyll a:b	Proline accumulation (µg g ⁻¹ fresh wt.)
I ₀	2.023 c	0.715 c	2.737 c	2.831 ab	194.209 a
I ₁	2.303 bc	0.809 bc	3.091 bc	2.859 a	182.271 b
I ₂	2.482 ab	0.883 ab	3.365 ab	2.811 ab	146.932 c
I ₃	2.635 a	1.012 a	3.573 a	2.709 b	127.494 d
CV (%)	2.071	12.547	2.579	5.365	6.598

In a column, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

Table 62a: Effect of variety on Chlorophyll and Proline content of wheat (2014-15)

Variety	Chlorophyll a (mg g ⁻¹)	Chlorophyll b (mg g ⁻¹)	Chlorophyll a+b (mg g ⁻¹)	Chlorophyll a:b	Proline accumulation (µg g ⁻¹ fresh wt.)
V ₁	2.317 a	0.816 a	3.134 a	2.843 a	159.511 a
V ₂	2.320 a	0.862 a	3.135 a	2.762 b	159.899 a
CV (%)	2.071	12.558	2.578	5.365	6.597

In a column, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

Table 62b: Effect of variety on Chlorophyll and Proline content of wheat (2015-16)

Variety	Chlorophyll a (mg g ⁻¹)	Chlorophyll b (mg g ⁻¹)	Chlorophyll a+b (mg g ⁻¹)	Chlorophyll a:b	Proline accumulation (µg g ⁻¹ fresh wt.)
V ₁	2.260 a	0.831 a	3.191 a	2.843 a	162.529 a
V ₂	2.362 a	0.878 a	3.192 a	2.762 b	162.924 a
CV (%)	2.071	12.547	2.579	5.365	6.598

In a column, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

Table 63a: Effect of nitrogen on Chlorophyll and Proline content of wheat (2014-15)

Nitrogen	Chlorophyll a (mg g ⁻¹)	Chlorophyll b (mg g ⁻¹)	Chlorophyll a+b (mg g ⁻¹)	Chlorophyll a:b	Proline accumulation (µg g ⁻¹ fresh wt.)
N ₀	1.913 b	0.680 b	2.593 b	2.816 ab	173.139 a
N ₁	2.014 b	0.703 b	2.718 b	2.869 a	163.419 ab
N ₂	2.615 a	0.927 a	3.542 a	2.824 ab	154.350 bc
N ₃	2.732 a	1.048 a	3.645 a	2.702 b	147.913 c
CV (%)	2.071	12.558	2.578	5.365	6.597

In a column, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

Table 63b: Effect of nitrogen on Chlorophyll and Proline content of wheat (2015-16)

Nitrogen	Chlorophyll a (mg g ⁻¹)	Chlorophyll b (mg g ⁻¹)	Chlorophyll a+b (mg g ⁻¹)	Chlorophyll a:b	Proline accumulation (µg g ⁻¹ fresh wt.)
N ₀	1.948 b	0.692 b	2.640 b	2.816 ab	176.414 a
N ₁	2.051 b	0.716 b	2.767 b	2.869 a	166.510 ab
N ₂	2.663 a	0.944 a	3.606 a	2.824 ab	157.270 ab
N ₃	2.782 a	1.067 a	3.752 a	2.702 b	150.712 b
CV (%)	2.071	12.547	2.579	5.365	6.598

In a column, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

Table 64a: Interaction effect of irrigation and nitrogen on Chlorophyll and Proline content of wheat (2014-15)

Interaction (Irrigation × Nitrogen)	Chlorophyll a (mg g ⁻¹)	Chlorophyll b (mg g ⁻¹)	Chlorophyll a+b (mg g ⁻¹)	Chlorophyll a:b	Proline accumulation (µg g ⁻¹ fresh wt.)
I ₀ N ₀	1.764 l	0.624 f	2.389 j	2.826 a	198.366 a
I ₀ N ₁	1.808 kl	0.641 f	2.450 j	2.821 a	195.147 a
I ₀ N ₂	2.144 e-g	0.758 d-f	2.902 e-g	2.831 a	187.786 b
I ₀ N ₃	2.232 e	0.785 c-f	3.017 e	2.845 a	180.869 c
I ₁ N ₀	1.883 jk	0.669 ef	2.552 ij	2.817 a	188.868 b
I ₁ N ₁	2.063 f-h	0.678 ef	2.744 gh	3.045 a	182.480 c
I ₁ N ₂	2.506 d	0.883 b-e	3.389 d	2.839 a	175.514 d
I ₁ N ₃	2.588 d	0.946 b-d	3.448 d	2.736 ab	168.842 e
I ₂ N ₀	1.948 ij	0.694 ef	2.641 hi	2.807 a	155.944 f
I ₂ N ₁	2.021 hi	0.723 d-f	2.744 gh	2.796 a	149.017 g
I ₂ N ₂	2.820 c	1.001 bc	3.821 c	2.817 a	138.268 h
I ₂ N ₃	2.969 b	1.051 b	4.020 b	2.824 a	133.609 h
I ₃ N ₀	2.057 gh	0.732 d-f	2.789 f-h	2.813 a	149.379 g
I ₃ N ₁	2.164 ef	0.769 c-f	2.933 ef	2.813 a	127.032 i
I ₃ N ₂	2.991 b	1.065 b	4.056 b	2.808 a	115.831 j
I ₃ N ₃	3.140 a	1.408 a	4.257 a	2.403 b	108.332 k
CV (%)	2.071	12.558	2.578	5.365	6.597

In a column, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

Table 64b: Interaction effect of irrigation and nitrogen on Chlorophyll and Proline content of wheat (2015-16)

Interaction (Irrigation × Nitrogen)	Chlorophyll a (mg g ⁻¹)	Chlorophyll b (mg g ⁻¹)	Chlorophyll a+b (mg g ⁻¹)	Chlorophyll a:b	Proline accumulation (µg g ⁻¹ fresh wt.)
I ₀ N ₀	1.796 l	0.636 f	2.431 j	2.826 a	202.184 a
I ₀ N ₁	1.841 kl	0.653 f	2.493 j	2.821 a	198.902 a
I ₀ N ₂	2.182 e-g	0.771 d-f	2.953 e-g	2.831 a	191.400 b
I ₀ N ₃	2.271 e	0.799 c-f	3.071 e	2.845 a	184.350 c
I ₁ N ₀	1.919 jk	0.681 ef	2.601 ij	2.817 a	192.399 b
I ₁ N ₁	2.103 f-h	0.691 ef	2.796 gh	3.045 a	185.892 c
I ₁ N ₂	2.554 d	0.900 b-e	3.454 d	2.839 a	178.795 d
I ₁ N ₃	2.637 d	0.964 b-d	3.513 d	2.736 ab	171.999 e
I ₂ N ₀	1.982 ij	0.706 ef	2.688 hi	2.807 a	158.888 f
I ₂ N ₁	2.057 hi	0.736 d-f	2.973 gh	2.796 a	151.830 g
I ₂ N ₂	2.870 c	1.019 bc	3.889 c	2.817 a	140.879 h
I ₂ N ₃	3.021 b	1.070 b	4.091 b	2.824 a	136.131 h
I ₃ N ₀	2.095 gh	0.745 d-f	2.840 f-h	2.813 a	152.185 g
I ₃ N ₁	2.203 ef	0.783 c-f	2.987 ef	2.813 a	129.418 i
I ₃ N ₂	3.045 b	1.085 b	4.130 b	2.808 a	118.007 j
I ₃ N ₃	3.197 a	1.434 a	4.334 a	2.403 b	110.367 k
CV (%)	2.071	12.547	2.579	5.365	6.598

In a column, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

4.6. Grain growth parameters

4.6.1. Number of spikelets spike⁻¹

The data regarding the spikelets spike⁻¹ of wheat as affected by different irrigation schedules are presented in Table 65a and Fig. 23a for first year (2014-15) and in Table 65b and Fig. 23b for second year (2015-16). Number of spikelets spike⁻¹ was significantly influenced by irrigation levels at different days after anthesis (DAA) in both the growing seasons. The highest number of spikelets spike⁻¹ was recorded in three irrigated plants (I₃) which was statistically similar with two irrigated plants (I₂) and the lowest number of spikelets spike⁻¹ was found in rain-fed (I₀) condition at all stages in both the years. Waraich *et al.* (2007) noticed that grain yield and all primary yields components increased linearly in response to irrigation. This result is corroborated with Abdorrahmani *et al.* (2005), Afzal *et al.* (2006), Bahadur (2008) and Mollah and Paul (2011) in barley, Rahman *et al.* (2001), Haider (2002), Rahman (2004), Naeem Sarwar *et al.* (2010), Muhammad *et al.* (2012), Atikullah *et al.* (2014) and Zaman *et al.* (2016) in wheat. Similar results were also observed by Ali and Amin (2007) in wheat where they found that irrigated plants had big effect on number of spikelets spike⁻¹. Sana Ullah Baloch *et al.* (2014) stated that decreasing irrigation number showed severe adverse effects on the number of grains panicle⁻¹. Mandic *et al.* (2014) stated that water stress during stem elongation stage reduced number of spikelets spike⁻¹. Similar results were also found by other researches (Sener *et al.*, 2000 and Gevrek and Atasoy 2012).

Number of spikelets spike⁻¹ varied significantly due to variety at different days after anthesis (DAA) in both the years and are shown in Table 66a for first year (2014-15) and in Table 66b for second year (2015-16). Between the two varieties, the higher number of spikelets spike⁻¹ was obtained in BARI Gom 24 (V₁) at different days after anthesis (DAA) in both the years.

The effects of split application of nitrogen was found significant in respect of number of spikelets spike⁻¹ at all stages in both the growing seasons and are shown in Table 67a and Fig. 24a for first year (2014-15) and Table 67b and Fig. 24b for second year (2015-16). Waraich *et al.* (2007) noticed that grain yield and all primary yields components increased linearly in response to nitrogen fertilizer. In every occasion, three split (N₂) applications of nitrogen had the highest number of spikelets spike⁻¹ which was statistically identical with four split (N₃) applications of nitrogen and the lowest value was found in control (N₀) in both the years. Similar result was also observed in wheat by many researchers (Maurya and Verma 1990, Singh *et al.*, 1992, Upadhyay and Tiwari 1996, Das 2002 and Islam *et al.*, 2011). Sarker *et al.* (2015) reported that efficient use of nitrogen during the grain filling stage enhanced number

of spikelets spike⁻¹. Rahman *et al.* (2014) noticed that the application of nitrogenous fertilizer increased filled spikelets spike⁻¹ over control. Similar results were observed by many authors (Modhej *et al.* 2008, Ali *et al.* 2011, Iqbal *et al.*, 2012 and Mandic *et al.*, 2014). The results are confirmed by Nerson (1980) who observed that the increasing N supply increased the number of filled spikelets due to promotion of the rate of spikelets initiation.

Different treatment combinations of irrigation and nitrogen had significant influence on number of spikelets spike⁻¹ of wheat at different days after anthesis (DAA) in both the growing seasons and are shown in 68a for first year (2014-15) and in Table 68b for second year (2015-16). From the table, it is obvious that the treatment combination of three irrigations (I₃) × three split (N₂) applications gave the highest number of spikelets spike⁻¹ which was statistically identical with I₃ × N₃ at all sampling dates in both the years. The lowest value was obtained in rain-fed (I₀) × control (N₀) at all the stages in both the years.

4.6.2. Number of grains spike⁻¹

The results in relation to number of grains spike⁻¹ of wheat as influenced by various irrigation treatments are shown in Table 65a and Fig. 25a for first year (2014-15) and in Table 65b and Fig. 25b for second year (2015-16). Irrigation treatments had significant effect on number of grain spike⁻¹ at all the days after anthesis in both the years. The highest number of grain spike⁻¹ was recorded in three irrigations (I₃) which was statistically similar with two (I₂) and one (I₁) irrigations and the lowest value was obtained in rain-fed (I₀) condition at all the stages in both the growing seasons. Similar result was reported in wheat by separate researchers (Yadav *et al.*, 2001, Pandit *et al.*, 2001, Abdorrahmani *et al.*, 2005, Shehzad *et al.*, 2012, Sana Ullah Baloch *et al.*, 2014 and Atikullah *et al.*, 2014) in wheat. Number of grains spike⁻¹ plays a vital role in grain yield (Abbate *et al.*, 1998 and Guarda *et al.*, 2004). Dokuyucu and Akkaya (1999) also found a positive effect between number of grain spike⁻¹ and grain yield in wheat. Mandal *et al.* (2005) noticed that the highest grain yield and seasonal ET increased significantly with an increase in water supply in every nutrient treatment, being highest in three irrigations. Razi-us Shams (2001) observed that the effect of irrigation treatments on yield and yield contributing characters were statistically significant. When irrigation frequency was increased the number of grains spike⁻¹ was gradually increased over control. This finding is corroborated with Khan *et al.* (2007), Muhammad *et al.* (2012), Sarker *et al.* (2015) and Zaman *et al.* (2016). Mishra and Padmakar (2010) reported that progressive increase in number of irrigations from 1 to 4 increased number of grain spike⁻¹ while three and four irrigations were found statistically at par with each other. Mollah

and Paul (2011) stated that I₂ (40 mm water as three times) irrigation produced the highest grain number per panicle weight and the lowest was in the control in barley. These finding is corroborated with Rahman and Paul (1998), Rahman *et al.* (2001) and Ngwako and Mashiqqa (2013) in wheat. Sana Ullah Baloch *et al.* (2014) stated that decreasing irrigation number showed severe adverse effects on the number of grains spike⁻¹.

Number of grain spike⁻¹ did not differ significantly due to variety at 14, 21, 28 and 35 DAA in both the years are given in 66a for first year (2014-15) and Table 66b for second year (2015-16). Between the two varieties, BARI Gom 24 was produced the highest number of grains spike⁻¹.

At 14, 21, 28 and 35 DAA, different split applications of nitrogen had significant effect on number of grains spike⁻¹ in both the years and are presented in Table 67a and Fig. 26a for first year (2014-15) and in Table 67b and Fig. 26b for second year (2015-16). At 14 DAA, the crop receiving nitrogen in three splits (N₂) produced the highest number of grains spike⁻¹ which was statistically identical to basal (N₁) and four (N₃) split applications of nitrogen in both the years. At 21 DAA, the highest number of grains spike⁻¹ was produced in three split (N₂) applications which were statistically at par with basal (N₁) and four (N₃) split applications of nitrogen in the first year (2014-15). At 28 and 35 DAA, the crop receiving nitrogen in three splits (N₂) produced the highest number of grains spike⁻¹ which was statistically at par with four split (N₃) applications of nitrogen in both the years. The lowest value at 14, 21, 28 and 35 DAA was found in control (N₀) in both the growing seasons. Naveed *et al.* (2013) reported that the number of grains spike⁻¹ increased with increase in the amount of nitrogen application. The reason of increased number of grains produced in plants receiving major portion of the nutrient after cut may be attributed to the positive role of nitrogen in cells expansion, enlargement and other and above the grain filling. Martre *et al.* (2003) reported decreased grain numbers under nitrogen deficiency conditions. Sohail *et al.* (2018) reported that no N fertilizer applied at tiller formation stage significantly reduced number of grains per spike. Singh *et al.* (1992) reported that nitrogen fertilization showed marked improvement in seeds spike⁻¹. Similar result was also found in wheat by many authors (Shehzad *et al.*, 2012 and Shirazi *et al.*, 2014). Oad *et al.* (2007) stated that split applications of N significantly produced more grain number of spike than other methods. Raigar and Pareek (2006) reported that grain spike⁻¹ did not differ significantly due to three split applications of nitrogen. Rahman *et al.* (2014) noticed that the application of nitrogenous fertilizer increased grains spike⁻¹ over control.

Table 65a: Effect of irrigation on number of spikelets spike⁻¹ and number of grain spike⁻¹ of wheat at day after anthesis (2014-15)

Irrigation	Number of spikelets spike ⁻¹					Number of grain spike ⁻¹			
	7 DAA	14 DAA	21 DAA	28 DAA	35 DAA	14 DAA	21 DAA	28 DAA	35 DAA
I ₀	14.938 c	15.292 c	15.500 c	15.500 c	15.604 c	39.167 b	40.021 b	40.469 b	41.218 b
I ₁	15.854 bc	16.083 bc	16.208 bc	16.313 bc	16.354 bc	43.563 ab	44.177 ab	44.583 ab	45.208 ab
I ₂	16.917 ab	17.000 ab	17.146 ab	17.271 ab	17.333 ab	45.219 a	45.917 a	46.281 a	47.052 a
I ₃	17.583 a	17.771 a	18.000 a	18.167 a	18.229 a	46.531 a	47.094 a	47.625 a	48.583 a
CV (%)	13.939	14.660	14.323	14.695	14.489	10.297	10.682	10.434	10.747

At specific days after anthesis, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

Table 65b: Effect of irrigation on number of spikelets spike⁻¹ and number of grain spike⁻¹ of wheat at day after anthesis (2015-16)

Irrigation	Number of spikelets spike ⁻¹					Number of grain spike ⁻¹			
	7 DAA	14 DAA	21 DAA	28 DAA	35 DAA	14 DAA	21 DAA	28 DAA	35 DAA
I ₀	15.438 c	15.792 c	16.000 c	16.000 c	16.104 c	40.583 b	41.250 b	41.896 b	42.667 b
I ₁	16.354 bc	16.583 bc	16.708 bc	16.813 bc	16.854 bc	45.000 ab	45.375 ab	46.125 ab	46.792 ab
I ₂	17.417 ab	17.500 ab	17.646 ab	17.771 ab	17.833 ab	46.750 a	47.125 a	47.854 a	48.667 a
I ₃	18.083 a	18.271 a	18.500 a	18.667 a	18.729 a	48.042 a	48.500 a	49.292 a	50.417 a
CV (%)	13.525	16.477	15.072	14.270	16.255	9.650	10.140	10.619	11.445

At specific days after anthesis, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

Table 66a: Effect of variety on number of spikelets spike⁻¹ and number of grain spike⁻¹ of wheat at day after anthesis (2014-15)

Variety	Number of spikelets spike ⁻¹					Number of grain spike ⁻¹			
	7 DAA	14 DAA	21 DAA	28 DAA	35 DAA	14 DAA	21 DAA	28 DAA	35 DAA
V ₁	17.021 a	17.260 a	17.406 a	17.521 a	17.635 a	43.979 a	44.667 a	45.120 a	46.021 a
V ₂	15.625 b	15.813 b	16.021 b	16.104 b	16.125 b	43.260 a	43.938 a	44.359 a	45.010 a
CV (%)	13.939	14.660	14.323	14.695	14.489	10.297	10.682	10.434	10.747

At specific days after anthesis, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

Table 66b: Effect of variety on number of spikelets spike⁻¹ and number of grain spike⁻¹ of wheat at day after anthesis (2015-16)

Variety	Number of spikelets spike ⁻¹					Number of grain spike ⁻¹			
	7 DAA	14 DAA	21 DAA	28 DAA	35 DAA	14 DAA	21 DAA	28 DAA	35 DAA
V ₁	17.521 a	17.760 a	17.906 a	18.021 a	18.135 a	45.510 a	45.969 a	46.729 a	47.719 a
V ₂	16.125 b	16.313 b	16.521 b	16.604 b	16.625 b	44.677 a	45.156 a	45.854 a	46.552 a
CV (%)	13.525	16.477	15.072	14.270	16.255	9.650	10.140	10.619	11.445

At specific days after anthesis, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

Table 67a: Effect of nitrogen on number of spikelets spike⁻¹ and number of grain spike⁻¹ of wheat at day after anthesis (2014-15)

Nitrogen	Number of spikelets spike ⁻¹					Number of grain spike ⁻¹			
	7 DAA	14 DAA	21 DAA	28 DAA	35 DAA	14 DAA	21 DAA	28 DAA	35 DAA
N ₀	13.938 c	14.021 c	14.125 c	14.167 c	14.188 c	32.677 b	33.385 b	33.688 c	34.177 c
N ₁	16.458 b	16.708 b	16.813 b	16.958 b	17.063 b	46.271 a	46.917 a	47.281 b	47.896 b
N ₂	17.854 a	18.104 a	18.375 a	18.438 a	18.521 a	48.198 a	48.958 a	49.615 a	51.031 a
N ₃	17.042 ab	17.313 ab	17.542 ab	17.688 ab	17.750 ab	47.333 a	47.948 a	48.375 ab	48.958 ab
CV (%)	13.939	14.660	14.323	14.695	14.489	10.297	10.682	10.434	10.747

At specific days after anthesis, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

Table 67b: Effect of nitrogen on number of spikelets spike⁻¹ and number of grain spike⁻¹ of wheat at day after anthesis (2015-16)

Nitrogen	Number of spikelets spike ⁻¹					Number of grain spike ⁻¹			
	7 DAA	14 DAA	21 DAA	28 DAA	35 DAA	14 DAA	21 DAA	28 DAA	35 DAA
N ₀	14.438 c	14.521 c	14.625 c	14.667 c	14.688 c	33.792 b	34.333 c	34.833 c	35.354 c
N ₁	16.958 b	17.208 b	17.313 b	17.458 b	17.563 b	47.854 a	48.125 b	48.750 b	49.542 b
N ₂	18.354 a	18.604 a	18.875 a	18.938 a	19.021 a	49.875 a	50.458 a	51.563 a	52.958 a
N ₃	17.542 ab	17.813 ab	18.042 ab	18.188 ab	18.250 ab	48.854 a	49.333 ab	50.021 ab	50.688 ab
CV (%)	13.525	16.477	15.072	14.270	16.255	9.650	10.140	10.619	11.445

At specific days after anthesis, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

Table 68a: Interaction effect of irrigation and nitrogen on number of spikelets spike⁻¹ and number of grain spike⁻¹ of wheat at day after anthesis (2014-15)

Interaction (Irrigation × Nitrogen)	Number of spikelets spike ⁻¹					Number of grain spike ⁻¹			
	7 DAA	14 DAA	21 DAA	28 DAA	35 DAA	14 DAA	21 DAA	28 DAA	35 DAA
I ₀ N ₀	12.500 i	12.750 h	12.917 h	12.917 j	13.000 i	29.250 j	30.250 j	30.708 j	31.292 k
I ₀ N ₁	15.250 fg	15.667 d-f	15.833 ef	15.833 f-h	15.917 e-g	41.667 g	42.250 g	42.708 g	43.292 h
I ₀ N ₂	16.417 d-f	16.833 b-e	17.000 de	17.000 d-g	17.083 c-f	43.333 g	44.417 f	44.917 f	46.125 fg
I ₀ N ₃	15.583 e-g	15.917 c-f	16.250 d-f	16.250 e-h	16.417 d-g	42.417 g	43.167 fg	43.542 fg	44.165 gh
I ₁ N ₀	13.500 hi	13.583 gh	13.750 gh	13.833 ij	13.833 hi	32.417 hi	33.000 i	33.167 i	33.542 j
I ₁ N ₁	16.083 d-g	16.333 c-f	16.417 d-f	16.500 d-g	16.583 d-g	46.000 f	46.625 e	46.958 e	47.417 ef
I ₁ N ₂	17.167 b-e	17.417 b-d	17.667 b-d	17.667 b-e	17.750 b-e	48.417 c-e	49.042 b-d	49.750 b-d	51.083 bc
I ₁ N ₃	16.667 c-f	17.000 b-e	17.000 de	17.250 c-f	17.250 b-e	47.417 ef	48.042 de	48.458 de	48.792 de
I ₂ N ₀	14.583 gh	14.583 f-h	14.667 f-h	14.667 h-j	14.667 g-i	33.917 hi	34.625 hi	34.875 hi	35.292 ij
I ₂ N ₁	17.000 b-e	17.083 b-d	17.167 c-e	17.333 c-f	17.500 b-e	47.917 d-f	48.667 cd	48.958 cd	49.750 cd
I ₂ N ₂	18.500 ab	18.583 ab	18.833 a-c	19.000 a-c	19.000 a-c	49.958 a-c	50.625 ab	51.208 ab	52.583 ab
I ₂ N ₃	17.583 b-d	17.750 a-c	17.917 b-d	18.083 b-d	18.167 b-d	49.083 b-e	49.750 b-d	50.083 b-d	50.583 b-d
I ₃ N ₀	15.167 f-h	15.167 e-g	15.167 fg	15.250 g-i	15.250 f-h	35.125 h	35.667 h	36.000 h	36.583 i
I ₃ N ₁	17.500 b-d	17.750 a-c	17.833 b-d	18.167 b-d	18.250 b-d	49.500 a-d	50.125 a-c	50.500 bc	51.125 bc
I ₃ N ₂	19.333 a	19.583 a	20.000 a	20.083 a	20.250 a	51.083 a	51.750 a	52.583 a	54.333 a
I ₃ N ₃	18.333 a-c	18.583 ab	19.000 ab	19.167 ab	19.167 ab	50.417 ab	50.833 ab	51.417 ab	52.292 ab
CV (%)	13.939	14.660	14.323	14.695	14.489	10.297	10.682	10.434	10.747

At specific days after anthesis, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

Table 68b: Interaction effect of irrigation and nitrogen on number of spikelets spike⁻¹ and number of grain spike⁻¹ of wheat at day after anthesis (2015)

Interaction (Irrigation × Nitrogen)	Number of spikelets spike ⁻¹					Number of grain spike ⁻¹			
	7 DAA	14 DAA	21 DAA	28 DAA	35 DAA	14 DAA	21 DAA	28 DAA	35 DAA
I ₀ N ₀	13.000 i	13.250 h	13.417 h	13.417 j	13.500 i	30.333 i	31.083 j	31.667 j	32.167 l
I ₀ N ₁	15.750 fg	16.167 d-f	16.333 ef	16.333 f-h	16.417 e-g	43.167 f	43.667 g	44.167 g	44.917 i
I ₀ N ₂	16.917 d-f	17.333 b-e	17.500 de	17.500 d-g	17.583 c-f	44.917 f	45.750 f	46.667 ef	47.833 gh
I ₀ N ₃	16.083 e-g	16.417 c-f	16.750 d-f	16.750 e-h	16.917 d-g	43.917 f	44.500 fg	45.083 fg	45.750 hi
I ₁ N ₀	14.000 hi	14.083 gh	14.250 gh	14.333 ij	14.333 hi	33.500 h	33.833 i	34.333 i	34.750 k
I ₁ N ₁	16.583 d-g	16.833 c-f	16.917 d-f	17.000 d-g	17.083 d-g	47.500 e	47.750 e	48.250 de	49.000 fg
I ₁ N ₂	17.667 b-e	17.917 b-d	18.167 b-d	18.167 b-e	18.250 b-e	50.083 b-d	50.500 cd	51.750 bc	52.917 b-d
I ₁ N ₃	17.167 c-f	17.500 b-e	17.500 de	17.750 c-f	17.750 b-e	48.917 de	49.417 de	50.167 cd	50.500 ef
I ₂ N ₀	15.083 gh	15.083 f-h	15.167 f-h	15.167 h-j	15.167 g-i	35.083 gh	35.583 hi	36.000 hi	36.500 jk
I ₂ N ₁	17.500 b-e	17.583 b-d	17.667 c-e	17.833 c-f	18.000 b-e	49.667 cd	49.833 d	50.500 c	51.333 de
I ₂ N ₂	19.000 ab	19.083 ab	19.333 a-c	19.500 a-c	19.500 a-c	51.583 a-c	52.083 a-c	53.167 ab	54.583 ab
I ₂ N ₃	18.083 b-d	18.250 a-c	18.417 b-d	18.583 b-d	18.667 b-d	50.667 b-d	51.000 b-d	51.750 bc	52.250 c-e
I ₃ N ₀	15.667 f-h	15.667 e-g	15.667 fg	15.750 g-i	15.750 f-h	36.250 g	36.833 h	37.333 h	38.000 j
I ₃ N ₁	18.000 b-d	18.250 a-c	18.333 b-d	18.667 b-d	18.750 b-d	51.083 a-c	51.250 b-d	52.083 bc	52.917 b-d
I ₃ N ₂	19.833 a	20.083 a	20.500 a	20.583 a	20.750 a	52.917 a	53.500 a	54.667 a	56.500 a
I ₃ N ₃	18.833 a-c	19.083 ab	19.500 ab	19.667 ab	19.667 ab	51.917 ab	52.417 ab	53.083 ab	54.250 bc
CV (%)	13.525	16.477	15.072	14.270	16.255	9.650	10.140	10.619	11.445

At specific days after anthesis, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

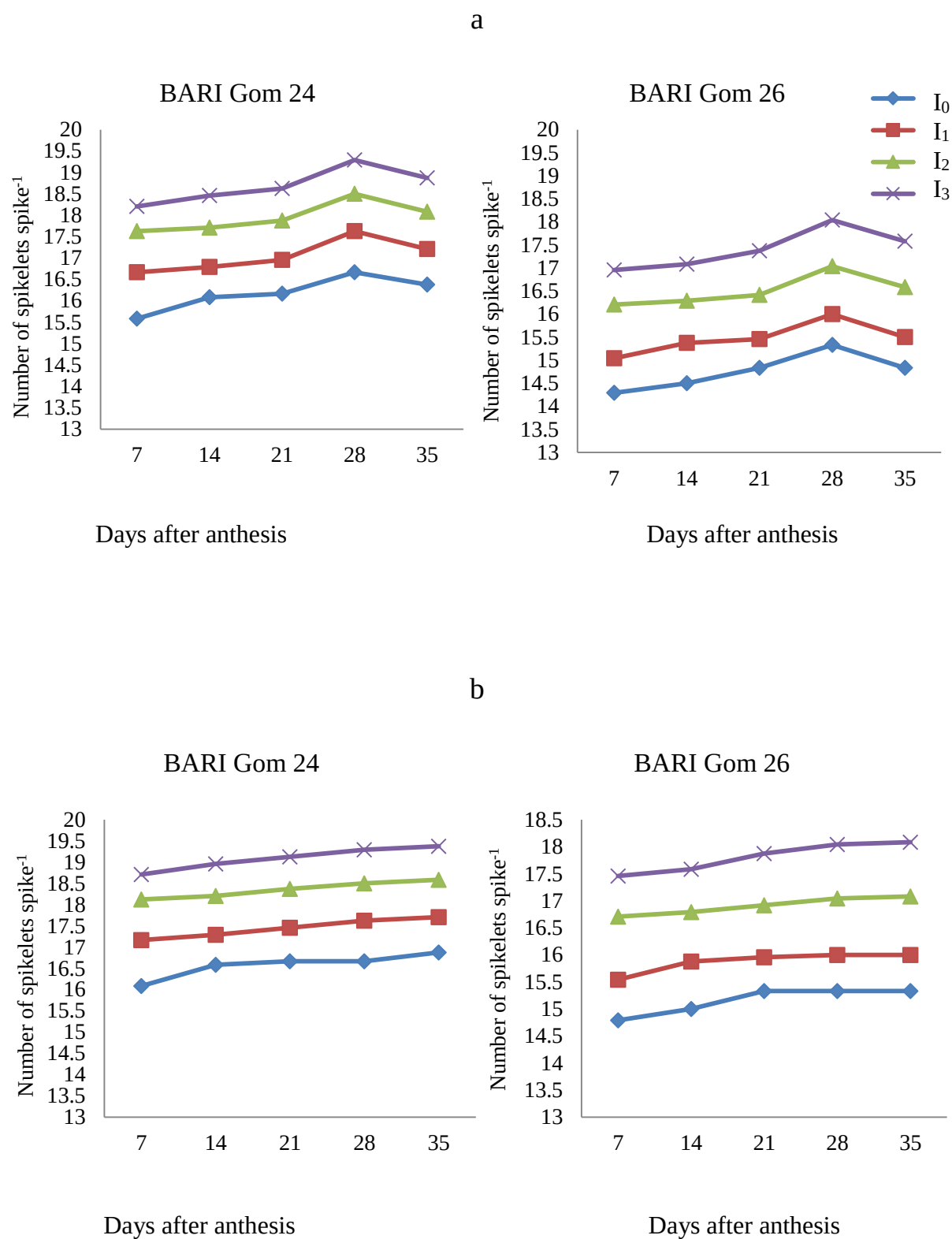


Fig. 23 Effect of irrigation on number of spikelets spike⁻¹ at different days after anthesis in 2014-15(a) and 2015-16(b)

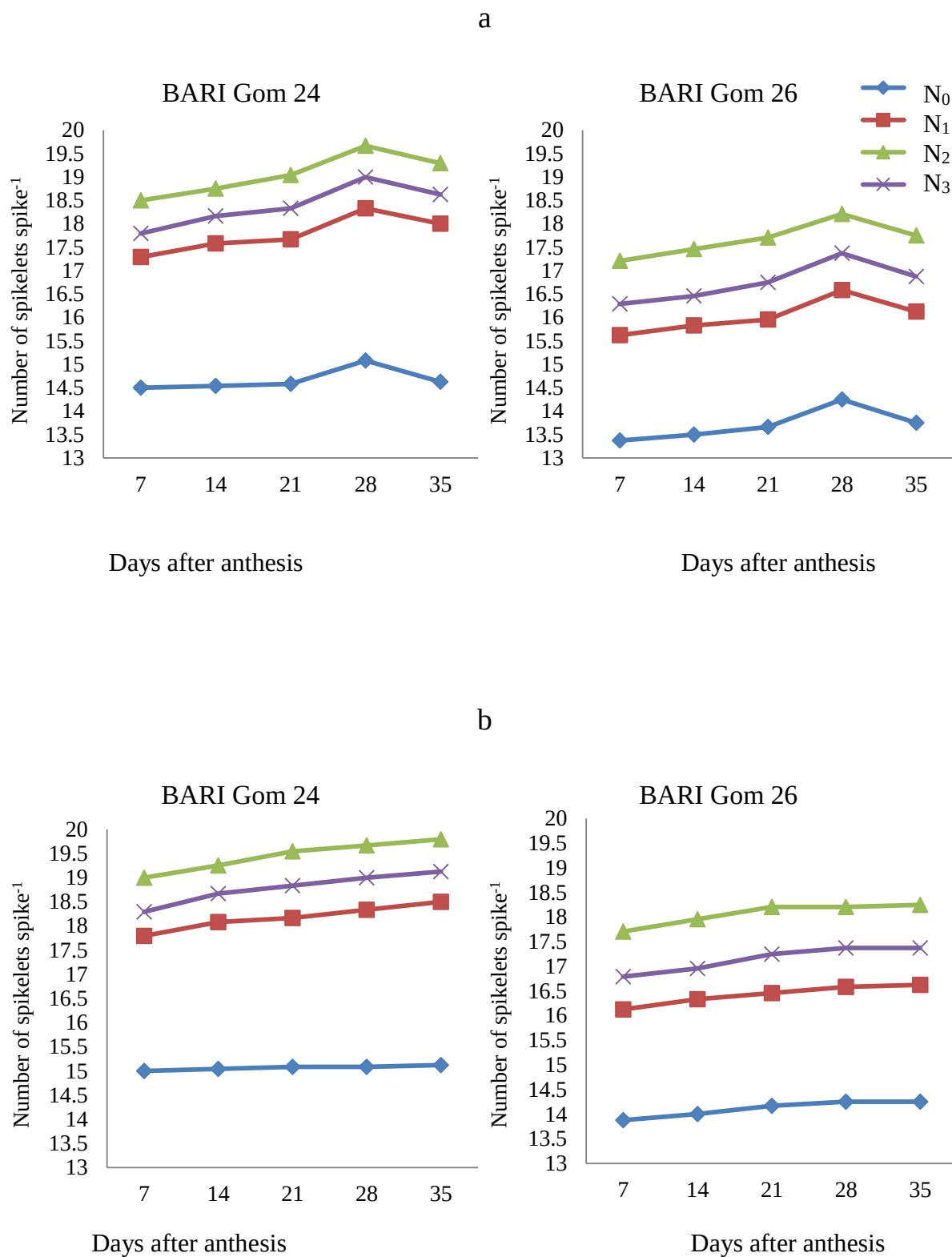


Fig. 24 Effect of nitrogen on number of spikelets spike⁻¹ at different days after anthesis in 2014-15(a) and 2015-16(b)

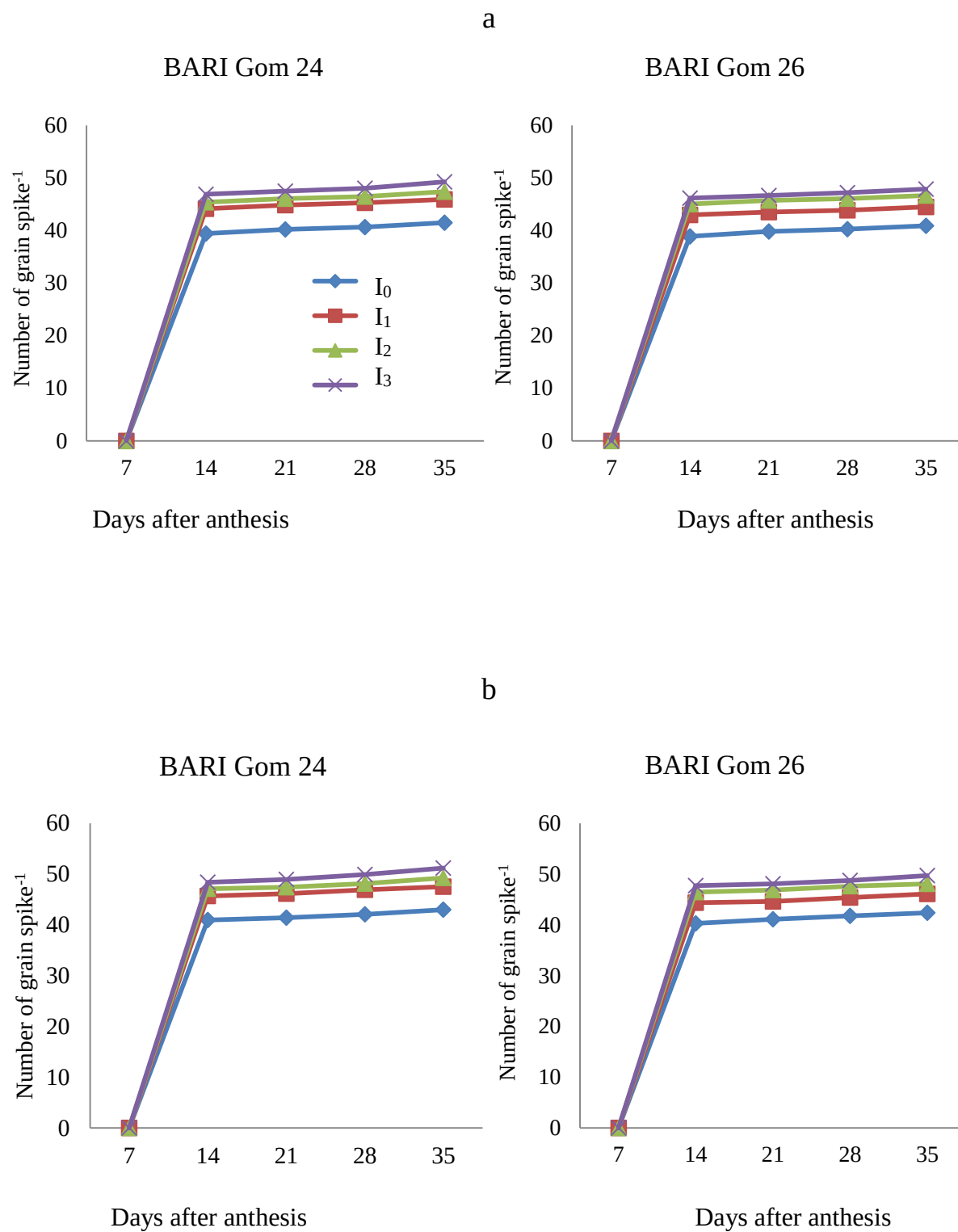


Fig. 25 Effect of irrigation on number of grain spike⁻¹ at different days after anthesis in 2014-15(a) and 2015-16(b)

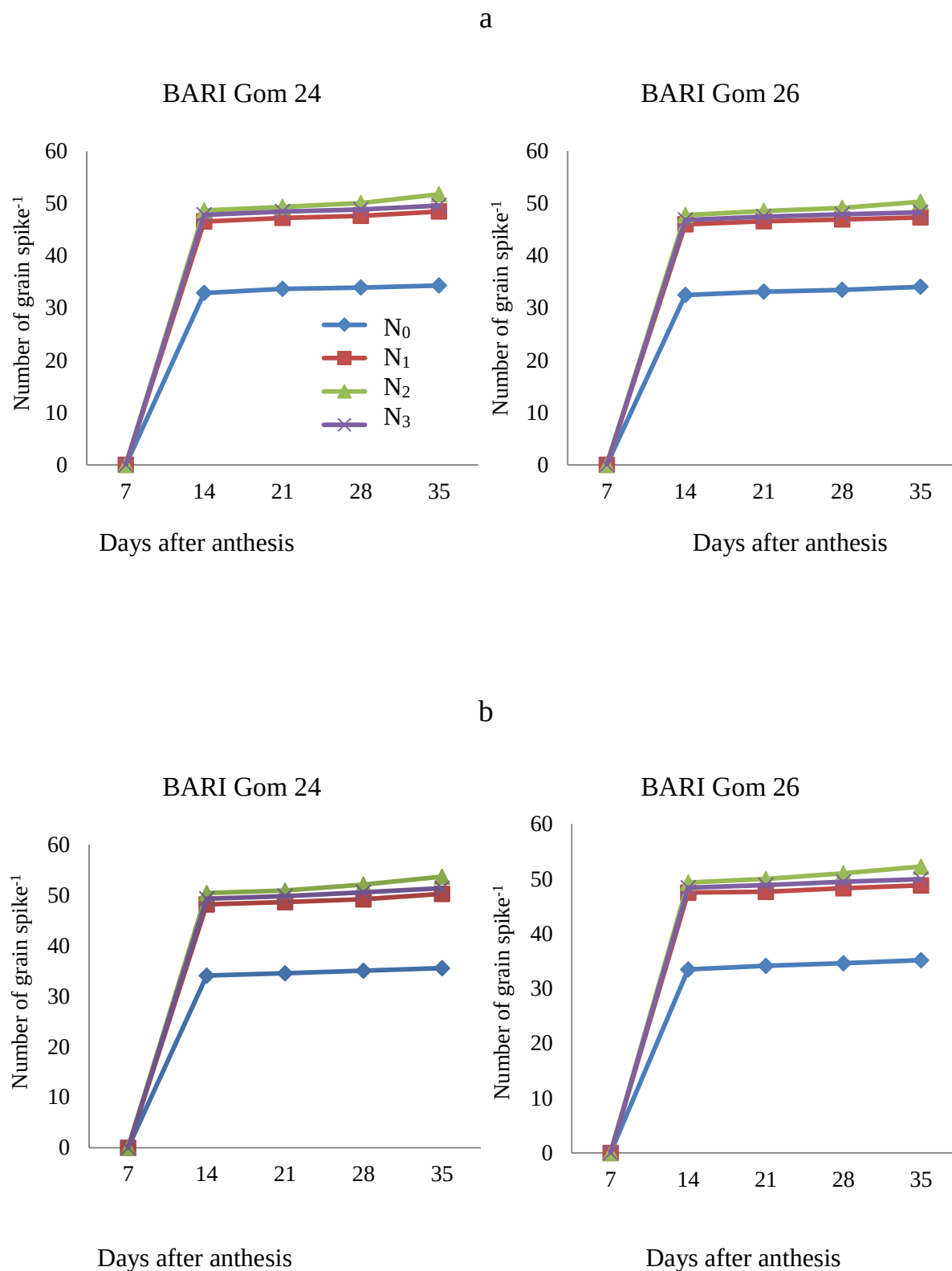


Fig. 26 Effect of nitrogen on number of grain spike⁻¹ at different days after anthesis in 2014-15(a) and 2015-16(b)

Different treatment combinations of irrigation and nitrogen had significant effects on number of grains spike⁻¹ of wheat at different days after anthesis (DAA) in both the growing seasons and are shown in Table 68a for first year (2014-15) and in Table 68b for second year (2015-16). From the table, it is obvious that the treatment combination of three irrigations (I_3) $\times$ three split (N_2) applications produced the highest number of grains spike⁻¹ which was statistically identical with $I_3 \times N_3$ at all sampling dates in both the years. The lowest value was obtained in rain-fed (I_0) $\times$ control (N_0) in both the growing seasons.

4.6.3. Dry weight of spike

There was a pronounced effect of different irrigations level on dry weight of spike at all the days after anthesis in both the growing seasons and are presented in Table 69a and Fig. 27a for first year (2014-15) and in Table 69b and Fig. 27b for second year (2015-16). Spike growth is fully dependent on the anthesis and grain filling duration. Significantly the highest dry weight of spike was recorded in three irrigations (I_3) followed by two (I_2) irrigations and the lowest value were observed in rain-fed (I_0) condition at all sampling dates in both the years. Similar results were found by Rahman and Paul (1996) and Rahman (2004) in wheat and they stated that the irrigated wheat plants had higher spike weight than the rain-fed plants at all the stages of growth. Spike weight increased with increasing time under irrigated condition but decreased by water deficiency in the soil (Rahman and Paul, 1998).

Varieties had no significant effect on dry weight of spike at 7, 14, 21, 28 and 35 DAA in both the years and are given in Table 70a for first year (2014-15) and in Table 70b for second year (2015-16). Between the two varieties, higher dry weight of spike was found in BARI Gom 24 than BARI Gom 26.

Dry weight of spike was significantly influenced by different split applications of nitrogen at all stages in both the years and are presented in Table 71a and Fig. 28a for first year (2014-15) and in Table 71b and Fig. 28b for second year (2015-16). At 7 DAA, significantly the highest dry weight of spike was observed in three split (N_2) applications of nitrogen in both the growing seasons. The crops receiving three split (N_2) applications of nitrogen produced the highest dry weight of spike which was statistically identical to basal (N_1) and four (N_3) split applications of nitrogen in both the years at 14, 21, 28 and 35 DAA. The lowest value was obtained in control (N_0) at all sampling dates in both the years. Similar results were found by Rahman (2004) in wheat.

Different treatment combinations of irrigation and nitrogen had significant influence on dry weight of spike in both the years at 7, 14, 21, 28 and 35 DAA and are given in Table 72a for first year (2014-15) and in Table 72b for second year (2015-16). From the table, it was observed that the treatment combination of three irrigations (I_3) $\times$ three split (N_2) applications of nitrogen produced the highest dry weight of spike than any other treatments combination in both the years at 7 DAA. In case of 14, 21, 28 and 35 DAA, the highest dry weight of spike was observed in the treatment combinations of three irrigations (I_3) $\times$ three split (N_2) applications of nitrogen which was statistically identical to three irrigations (I_3) $\times$ basal (N_1) and three irrigations (I_3) $\times$ four (N_3) split applications of nitrogen in both the years. The lowest value was found in rain-fed (I_0) $\times$ control (N_0) at all the sampling dates in both the years.

4.6.4. Dry weight grain⁻¹

Irrigation levels showed significant effect on dry weight grain⁻¹ in both the growing seasons at 14, 21, 28 and 35 DAA and are presented in Table 69a and Fig. 29a for first year (2014-15) and in Table 69b and Fig. 29b for second year (2015-16). Irrigated plants had higher dry weight grain⁻¹ than the rain-fed plants. At 14 DAA, the highest dry weight grain⁻¹ was in the three irrigations (I_3) treatment which was statistically at par with two irrigations (I_2) treatment in both the years. Significantly the highest dry weight grain⁻¹ was obtained in three irrigated plants (I_3) which was statistically identical with two irrigations (I_2) in both the growing seasons at 21, 28 and 35 DAA. The lowest value was found in rain-fed (I_0) condition at all stages in both the years. Similar results were also stated by Machado and Paulsen (2001), Haider (2002) and Rahman (2004) in wheat and Bahadur (2008) in barley. Grain weight ear⁻¹ is dependent on the number of grains and its size and shape (Amin *et al.*, 1995). Dry weight of grains was significantly affected by water stress (Rahman and Paul, 1996). Water stress during meiosis in microspore mother cells of wheat induced male sterility which resulted in reduced grain yield (Lalonde *et al.*, 1997). Drought and high temperature are major factors limiting crop production. Crops maintain nearly stable water relations regardless of temperature when moisture is ample, but high temperature strongly affects water relations when water is limited.

Dry weight grain⁻¹ did not differ significantly due to variety at 14, 21, 28 and 35 DAA in both the years and are shown in Table 70a for first year (2014-15) and in Table 70b for second year (2015-16). But some superiority in BARI Gom 24 was observed over BARI Gom 26.

Split applications of nitrogen had significant effect on dry weight grain⁻¹ at all stages in both the growing seasons and are given in Table 71a and Fig. 30a for first year (2014-15) and in Table 71b and Fig. 30b for second year (2015-16). Significantly the highest dry weight grain⁻¹ at 14, 21, 28 and 35 DAA were recorded in three splits (N₂) application of nitrogen which was statistically similar with four split (N₃) applications of nitrogen and the lowest value at 14, 21, 28 and 35 DAA were found in control (N₀) in both the years. Similar results were found by Rahman (2004) in wheat.

Dry weight grain⁻¹ showed statistically significant variation at all stages by the interaction of irrigation and nitrogen in both the years and are given in Table 72a for first year (2014-15) and in Table 72b for second year (2015-16). From the table, it was observed that the treatment combination of three irrigations (I₃) × three splits (N₂) application of nitrogen produced the highest dry weight grain⁻¹ than any other treatment combinations in both the years and the lowest value at 14, 21, 28 and 35 DAA were obtained in rain-fed (I₀) × control (N₀) in both the growing seasons.

Table 69a: Effect of irrigation on dry weight of spike and dry weight grain⁻¹ of wheat at day after anthesis (2014-15)

Irrigation	Dry Weight of spike (g)					Dry weight grain ⁻¹ (mg)			
	7 DAA	14 DAA	21 DAA	28 DAA	35 DAA	14 DAA	21 DAA	28 DAA	35 DAA
I ₀	0.843 c	1.245 c	1.580 c	1.881 c	2.201 c	13.942 b	24.298 c	28.376 c	31.186 c
I ₁	0.926 b	1.387 b	1.761 b	2.095 b	2.452 b	14.673 ab	26.197 b	31.024 bc	34.591 b
I ₂	0.985 ab	1.489 b	1.891 b	2.250 b	2.633 b	15.111 a	27.175 ab	33.036 ab	36.832 ab
I ₃	1.019 a	1.690 a	2.146 a	2.554 a	2.988 a	15.449 a	28.421 a	34.407 a	38.468 a
CV (%)	2.160	2.297	2.284	2.315	2.298	7.674	4.477	3.673	4.583

At specific days after anthesis, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

Table 69b: Effect of irrigation on dry weight of spike and dry weight grain⁻¹ of wheat at day after anthesis (2015-16)

Irrigation	Dry Weight of spike (g)					Dry weight grain ⁻¹ (mg)			
	7 DAA	14 DAA	21 DAA	28 DAA	35 DAA	14 DAA	21 DAA	28 DAA	35 DAA
I ₀	0.858 c	1.268 c	1.610 c	1.916 c	2.242 c	14.193 b	24.727 c	28.907 c	31.786 c
I ₁	0.944 b	1.413 b	1.794 b	2.135 b	2.498 b	14.938 ab	26.660 b	31.605 bc	35.256 b
I ₂	1.00 ab	1.517 b	1.927 b	2.293 b	2.683 b	15.383 a	27.655 ab	33.654 ab	37.541 ab
I ₃	1.038 a	1.722 a	2.187 a	2.602 a	3.044 a	15.728 a	28.922 a	35.051 a	39.208 a
CV (%)	2.161	2.306	2.299	2.291	2.29	7.671	4.480	3.672	4.584

At specific days after anthesis, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

Table 70a: Effect of variety on dry weight of spike and dry weight grain⁻¹ of wheat at day after anthesis (2014-15)

Variety	Dry Weight of spike (g)					Dry weight grain ⁻¹ (mg)			
	7 DAA	14 DAA	21 DAA	28 DAA	35 DAA	14 DAA	21 DAA	28 DAA	35 DAA
V ₁	0.951 a	1.465 a	1.860 a	2.213 a	2.590 a	14.832 a	26.844 a	32.053 a	35.558 a
V ₂	0.935 a	1.441 a	1.829 a	2.177 a	2.547 a	14.756 a	26.200 a	31.369 a	34.980 a
CV (%)	2.160	2.297	2.284	2.315	2.298	7.674	4.477	3.673	4.583

At specific days after anthesis, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

Table 70b: Effect of variety on dry weight of spike and dry weight grain⁻¹ of wheat at day after anthesis (2015-16)

Variety	Dry Weight of spike (g)					Dry weight grain ⁻¹ (mg)			
	7 DAA	14 DAA	21 DAA	28 DAA	35 DAA	14 DAA	21 DAA	28 DAA	35 DAA
V ₁	0.969 a	1.492 a	1.895 a	2.255 a	2.639 a	15.099 a	27.319 a	32.652 a	36.242 a
V ₂	0.953 a	1.467 a	1.864 a	2.218 a	2.595 a	15.022 a	26.664 a	31.956 a	35.653 a
CV (%)	2.161	2.306	2.299	2.291	2.29	7.671	4.480	3.672	4.584

At specific days after anthesis, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

Table 71a: Effect of nitrogen on dry weight of spike and dry weight grain⁻¹ of wheat at day after anthesis (2014-15)

Nitrogen	Dry Weight of spike (g)					Dry weight grain ⁻¹ (mg)			
	7 DAA	14 DAA	21 DAA	28 DAA	35 DAA	14 DAA	21 DAA	28 DAA	35 DAA
N ₀	0.802 c	1.175 b	1.492 b	1.776 b	2.078 b	13.013 c	22.716 c	26.008 c	28.533 c
N ₁	0.962 b	1.533 a	1.946 a	2.316 a	2.711 a	15.152 b	27.023 b	32.545 b	36.219 b
N ₂	1.029 a	1.558 a	1.978 a	2.354 a	2.755 a	15.710 a	28.712 a	34.840 a	39.034 a
N ₃	0.980 ab	1.545 a	1.961 a	2.334 a	2.731 a	15.301 ab	27.640 ab	33.450 ab	37.290 ab
CV (%)	2.160	2.297	2.284	2.315	2.298	7.674	4.477	3.673	4.583

At specific days after anthesis, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

Table 71b: Effect of nitrogen on dry weight of spike and dry weight grain⁻¹ of wheat at day after anthesis (2015-16)

Nitrogen	Dry Weight of spike (g)					Dry weight grain ⁻¹ (mg)			
	7 DAA	14 DAA	21 DAA	28 DAA	35 DAA	14 DAA	21 DAA	28 DAA	35 DAA
N ₀	0.817 c	1.197 b	1.521 b	1.810 b	2.117 b	13.247 c	23.117 c	26.495 c	29.083 c
N ₁	0.980 b	1.562 a	1.983 a	2.360 a	2.761 a	15.425 b	27.500 b	33.154 b	36.916 b
N ₂	1.048 a	1.587 a	2.016 a	2.399 a	2.806 a	15.993 a	29.219 a	35.492 a	39.785 a
N ₃	0.999 ab	1.573 a	1.998 a	2.378 a	2.782 a	15.577 ab	28.128 ab	34.076 ab	38.007 ab
CV (%)	2.161	2.306	2.299	2.291	2.29	7.671	4.480	3.672	4.584

At specific days after anthesis, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

Table 72a: Interaction effect of irrigation and nitrogen on dry weight of spike and dry weight grain⁻¹ of wheat at day after anthesis (2014-15)

Interaction (Irrigation × Nitrogen)	Dry Weight of spike (g)					Dry weight grain ⁻¹ (mg)			
	7 DAA	14 DAA	21 DAA	28 DAA	35 DAA	14 DAA	21 DAA	28 DAA	35 DAA
I ₀ N ₀	0.643 j	1.023 f	1.299 f	1.546 f	1.809 f	12.347 m	21.566 j	24.002 l	25.971 j
I ₀ N ₁	0.889 h	1.306 d	1.659 d	1.974 d	2.310 d	14.307 i	24.768 fg	28.839 hi	31.414 g
I ₀ N ₂	0.928 g	1.331 d	1.690 d	2.011 d	2.353 d	14.715 gh	25.772 ef	30.913 fg	34.548 e
I ₀ N ₃	0.911 gh	1.318 d	1.673 d	1.992 d	2.331 d	14.398 hi	25.085 f	29.751 gh	32.809 f
I ₁ N ₀	0.750 i	1.202 e	1.526 e	1.816 e	2.125 e	12.800 l	22.419 ij	25.336 k	28.009 i
I ₁ N ₁	0.944 fg	1.436 c	1.823 c	2.169 c	2.538 c	14.959 fg	26.416 e	31.778 ef	35.472 e
I ₁ N ₂	1.041 bc	1.464 c	1.859 c	2.212 c	2.588 c	15.671 cd	28.418 cd	34.186 d	38.285 c
I ₁ N ₃	0.970 ef	1.446 c	1.836 c	2.185 c	2.557 c	15.264 ef	27.535 d	32.797 e	36.598 d
I ₂ N ₀	0.880 h	1.225 e	1.556 e	1.851 e	2.166 e	13.235 k	23.123 hi	26.920 j	29.608 h
I ₂ N ₁	0.996 de	1.565 b	1.987 b	2.364 b	2.767 b	15.455 de	27.755 d	34.018 d	38.004 c
I ₂ N ₂	1.056 ab	1.587 b	2.015 b	2.398 b	2.806 b	16.119 ab	29.829 ab	36.520 b	40.918 b
I ₂ N ₃	1.007 cd	1.580 b	2.006 b	2.387 b	2.794 b	15.637 c-e	27.993 d	34.685 cd	38.800 c
I ₃ N ₀	0.935 g	1.251 e	1.589 e	1.890 e	2.212 e	13.669 j	23.756 gh	27.775 ij	30.548 gh
I ₃ N ₁	1.018 cd	1.826 a	2.318 a	2.758 a	3.228 a	15.889 bc	29.152 bc	35.546 bc	39.985 b
I ₃ N ₂	1.090 a	1.850 a	2.349 a	2.796 a	3.271 a	16.334 a	30.828 a	37.739 a	42.386 a
I ₃ N ₃	1.034 bc	1.834 a	2.328 a	2.771 a	3.242 a	15.905 bc	29.946 ab	36.569 ab	40.953 b
CV (%)	2.160	2.297	2.284	2.315	2.298	7.674	4.477	3.673	4.583

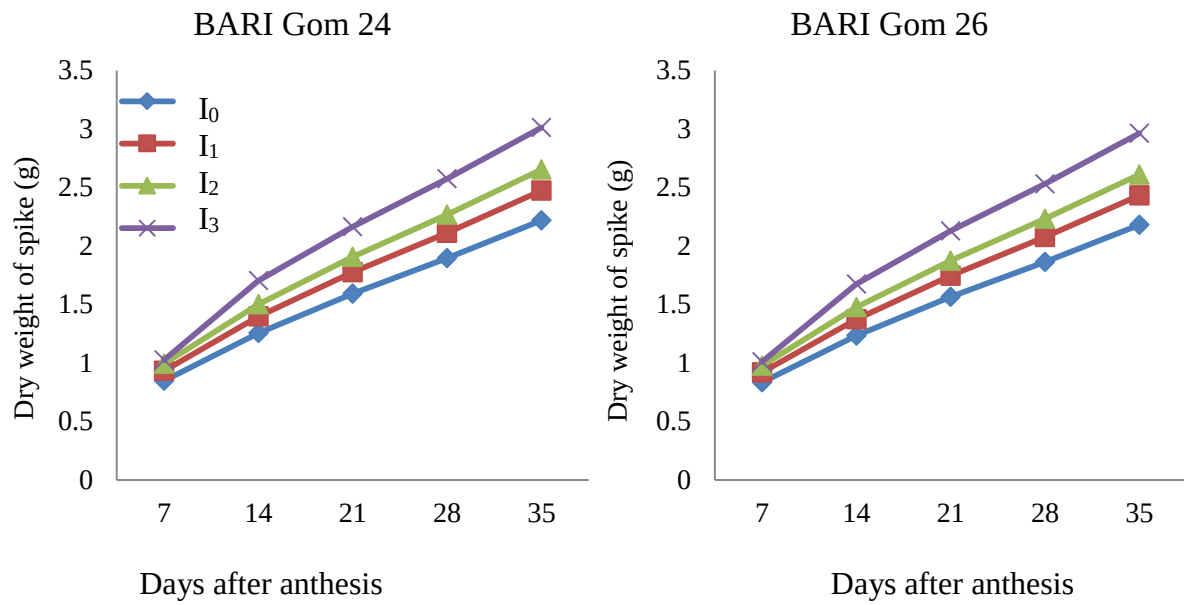
At specific days after anthesis, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

Table 72b: Interaction effect of irrigation and nitrogen on dry weight of spike and dry weight grain⁻¹ of wheat at day after anthesis (2015-16)

Interaction (Irrigation × Nitrogen)	Dry Weight of spike (g)					Dry weight grain ⁻¹ (mg)			
	7 DAA	14 DAA	21 DAA	28 DAA	35 DAA	14 DAA	21 DAA	28 DAA	35 DAA
I ₀ N ₀	0.655 j	1.042 f	1.324 f	1.576 f	1.843 f	12.570 m	21.947 j	24.452 l	26.471 j
I ₀ N ₁	0.906 h	1.331 d	1.690 d	2.011 d	2.353 d	14.564 i	25.206 fg	29.378 hi	32.019 g
I ₀ N ₂	0.945 g	1.356 d	1.722 d	2.049 d	2.397 d	14.980 gh	26.227 ef	31.492 fg	35.213 e
I ₀ N ₃	0.928 gh	1.343 d	1.705 d	2.029 d	2.374 d	14.658 hi	25.528 f	30.308 gh	33.440 f
I ₁ N ₀	0.764 i	1.224 e	1.555 e	1.850 e	2.165 e	13.030 l	22.816 ij	25.810 k	28.548 i
I ₁ N ₁	0.962 fg	1.462 c	1.857 c	2.210 c	2.586 c	15.229 fg	26.883 e	32.372 ef	36.154 e
I ₁ N ₂	1.060 bc	1.491 c	1.894 c	2.254 c	2.637 c	15.953 cd	28.920 cd	34.826 d	39.022 c
I ₁ N ₃	0.988 ef	1.473 c	1.871 c	2.226 c	2.605 c	15.539 ef	28.022 d	33.411 e	37.301 d
I ₂ N ₀	0.896 h	1.248 e	1.585 e	1.886 e	2.207 e	13.473 k	23.530 hi	27.424 j	30.178 h
I ₂ N ₁	1.015 de	1.594 b	2.024 b	2.409 b	2.819 b	15.733 de	28.246 d	34.655 d	38.736 c
I ₂ N ₂	1.076 ab	1.617 b	2.053 b	2.443 b	2.859 b	16.410 ab	30.356 ab	37.203 b	41.705 b
I ₂ N ₃	1.026 cd	1.610 b	2.044 b	2.433 b	2.846 b	15.919 c-e	28.488 d	35.334 cd	39.547 c
I ₃ N ₀	0.952 g	1.275 e	1.619 e	1.926 e	2.254 e	13.915 j	24.175 gh	28.295 ij	31.136 gh
I ₃ N ₁	1.036 cd	1.860 a	2.362 a	2.811 a	3.288 a	16.176 bc	29.667 bc	36.211 bc	40.754 b
I ₃ N ₂	1.111 a	1.885 a	2.393 a	2.849 a	3.333 a	16.629 a	31.373 a	38.445 a	43.201 a
I ₃ N ₃	1.053 bc	1.868 a	2.372 a	2.823 a	3.303 a	16.192 bc	30.475 ab	37.253 ab	41.741 b
CV (%)	2.161	2.306	2.299	2.291	2.29	7.671	4.480	3.672	4.584

At specific days after anthesis, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

a



b

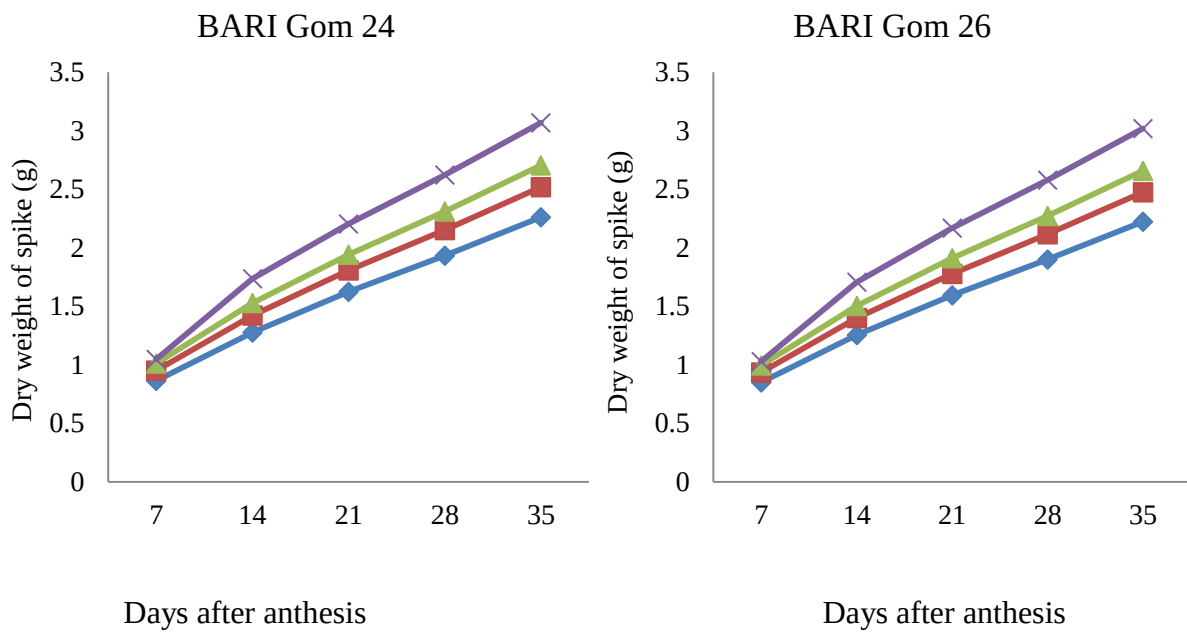


Fig. 27 Effect of irrigation on dry weight of spike at different days after anthesis in 2014-15(a) and 2015-16(b)

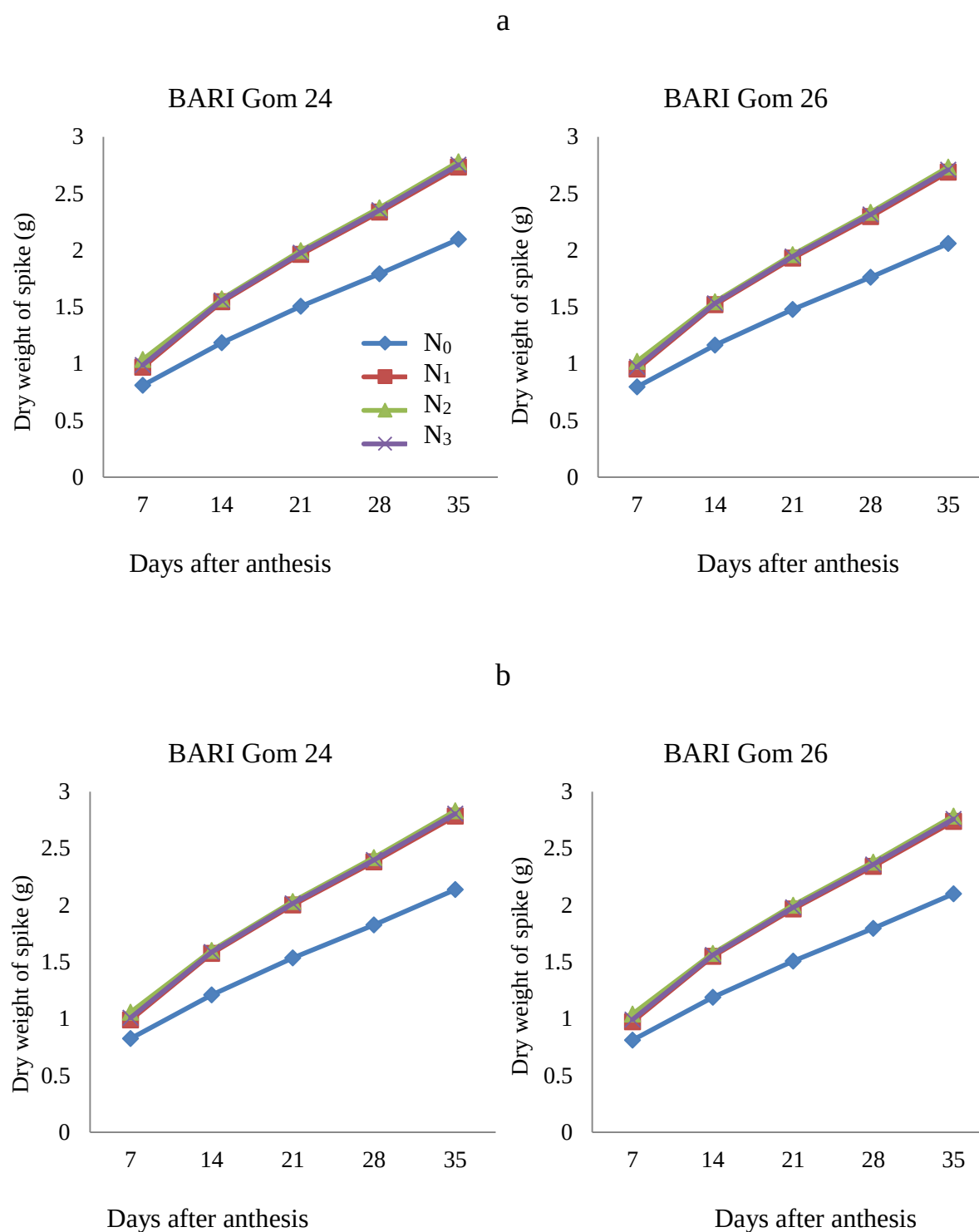
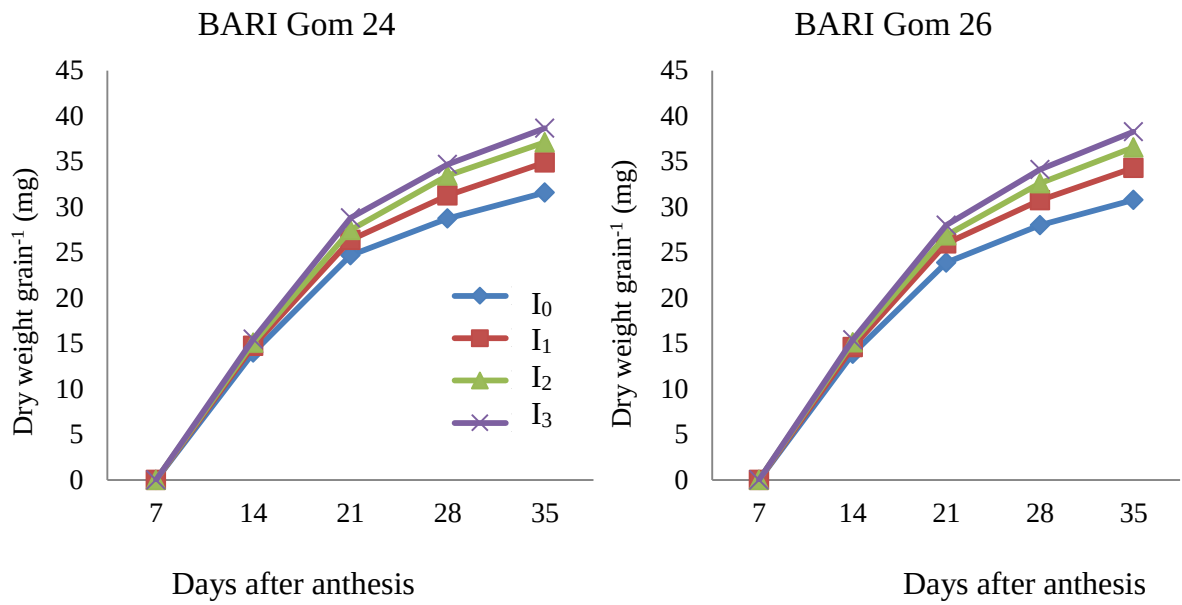


Fig. 28 Effect of nitrogen on dry weight of spike at different days after anthesis in 2014-15(a) and 2015-16(b)

a



b

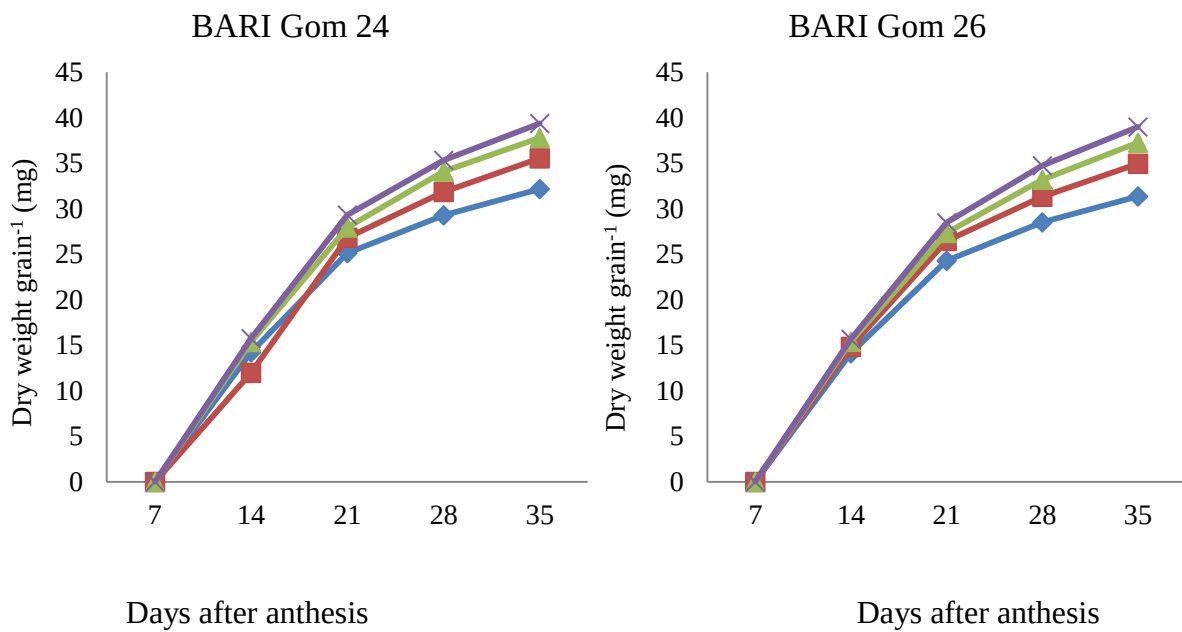


Fig. 29 Effect of irrigation on dry weight grain⁻¹ at different days after anthesis in 2014-15(a) and 2015-16(b)

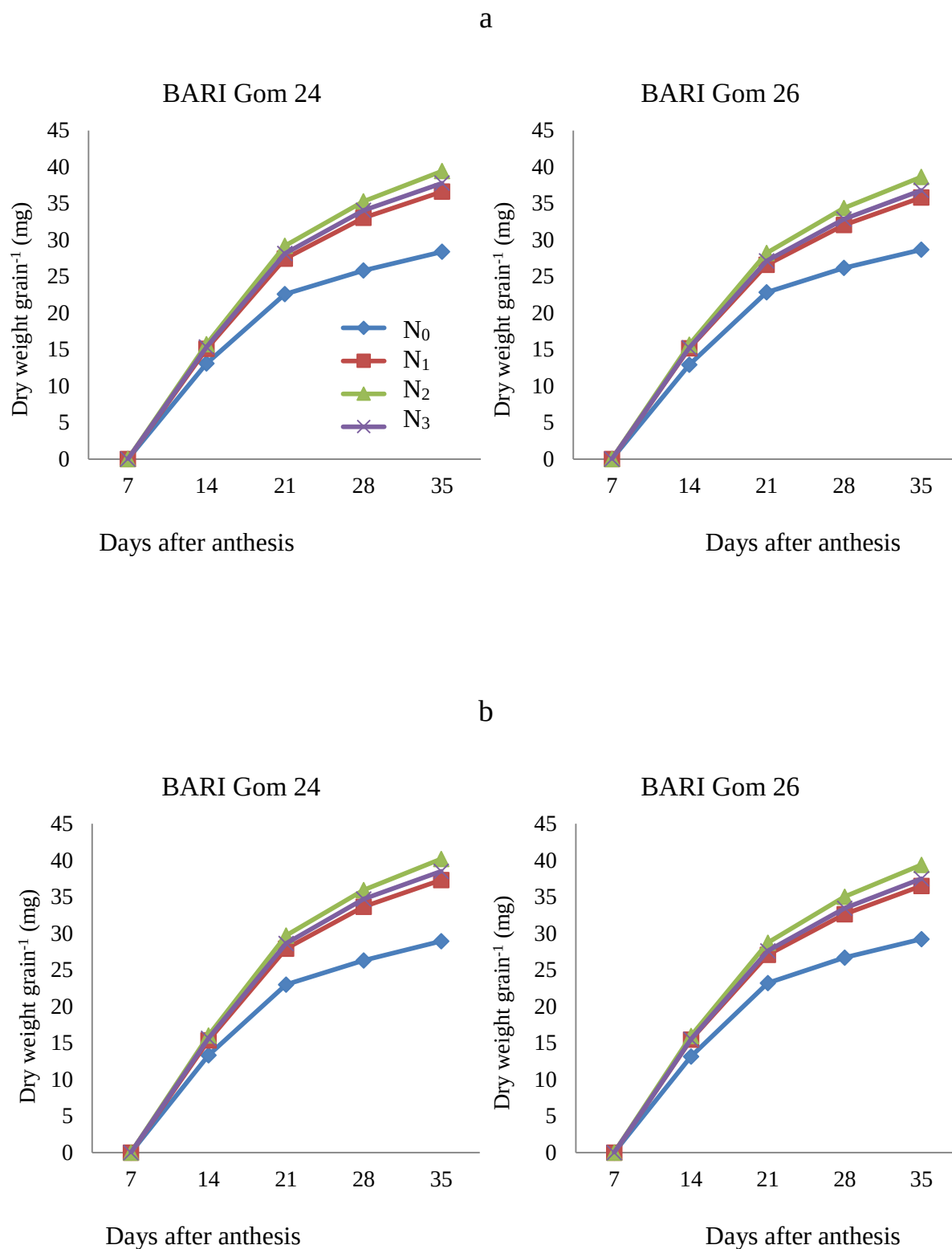


Fig. 30 Effect of nitrogen on dry weight grain⁻¹ at different days after anthesis in 2014-15(a) and 2015-16(b)

4.6.5. Grain growth rate

Grain growth rate varied significantly during the period of 7-14, 14-21, 21-28 and 28-35 DAA due to different irrigation levels in both the years and are presented in Table 73a and Fig. 31a for first year (2014-15) and in Table 73b and Fig. 31b for second year (2015-16). The irrigated plants had higher grain growth rate than the rain-fed plants. During the period of 7-14, 14-21 and 21-28 DAA, the highest grain growth rate was observed in three irrigated plant (I_3) which was statistically similar to two irrigated (I_2) plant in both the years. During the period of 28-35 DAA, the highest grain growth rate was observed in three irrigated plant (I_3) which was statistically identical with two (I_2) and one (I_1) irrigated plants in both the growing seasons. During the period of 7-14, 14-21, 21-28 and 28-35 DAA, the lowest value was obtained in rain-fed (I_0) condition in both the years. In every case the highest grain growth rate was observed at 7-14 DAA and soon after followed by a sharp decrease of grain growth rate in both the years. Reduction of grain yield under water stress was not due to effects on photosynthetic rate but due to vein loading (Wardlaw 1994). It is convenient to distinguish two sources of assimilate supply for grain growth; photosynthesis after anthesis and translocation of materials assimilated before anthesis and temporarily stored before moving to the grain. If cereals were to yield well where drought and high temperatures during grain filling were frequent, varieties must be bred which not only increase the rate but also sustain the duration of grain growth (Gallagher 1976). The reduction in duration of grain growth was the most important cause of reduced grain weight at maturity under drought alone or combined with high temperature (Savin and Nicolas 1996).

During the total grain growth periods, varieties had no significant effect on grain growth rate in both the years and are given in Table 74a for first year (2014-15) and Table 74b for second year (2015-16). Between the two varieties, higher grain growth rate was found in BARI Gom 24 than BARI Gom 26.

During the period of 7-14, 14-21, 21-28 and 28-35 DAA, grain growth rate was significantly influenced by split applications of nitrogen in both the years and are present in Table 75a and Fig. 32a for first year (2014-15) and in Table 75b and Fig. 32b for second year (2015-16). During the period of 7-14, 14-21 and 28-35 DAA, the highest grain growth rate was observed in three split (N_2) applications of nitrogen which was statistically similar with four split (N_3) applications of nitrogen in both the years. During the period of 21-28 DAA, the result revealed that the highest grain growth rate was obtained in three split (N_2) applications which were statistically identical to basal (N_1) and four split (N_3) applications of nitrogen in both the

growing seasons. During the period of 7-14, 14-21, 21-28 and 28-35 DAA, the lowest value were recorded in control (N_0) in both the years.

Different treatment combinations of irrigation and nitrogen had significant influence on grain growth rate during the period of 7-14, 14-21, 21-28 and 28-35 DAA in both the years which are given in Table 76a for first year (2014-15) and in Table 76b for second year (2015-16). During the period of 7-14, 14-21 and 21-28 DAA, the highest grain growth rate was recorded by treatment combinations of three irrigations (I_3) $\times$ three splits (N_2) application of nitrogen and the lowest values were obtained in rain-fed (I_0) $\times$ control (N_0) in both the years. During the period of 28-35 DAA, the result revealed that the highest grain growth rate was observed in three irrigations (I_3) $\times$ three splits (N_2) of nitrogen which was statistically identical with three irrigations (I_3) $\times$ basal (N_1) and the lowest value was obtained in rain-fed (I_0) $\times$ control (N_0) in both the years.

Table 73a: Effect of irrigation grain growth rate of wheat at day after anthesis (2014-15)

Irrigation	Grain growth rate (mg grain ⁻¹ day ⁻¹)			
	7-14 DAA	14-21 DAA	21-28 DAA	28-35 DAA
I ₀	1.992 b	1.478 c	0.587 b	0.403 b
I ₁	2.096 ab	1.645 b	0.694 b	0.512 a
I ₂	2.159 a	1.722 ab	0.842 a	0.545 a
I ₃	2.207 a	1.851 a	0.860 a	0.583 a
CV (%)	7.664	5.536	14.535	2.324

At specific days after anthesis, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

Table 73b: Effect of irrigation on grain growth rate of wheat at day after anthesis (2015-16)

Irrigation	Grain growth rate (mg grain ⁻¹ day ⁻¹)			
	7-14 DAA	14-21 DAA	21-28 DAA	28-35 DAA
I ₀	2.028 b	1.505 c	0.597 b	0.411 b
I ₁	2.134 ab	1.675 b	0.706 b	0.522 a
I ₂	2.198 a	1.753 ab	0.857 a	0.555 a
I ₃	2.247 a	1.885 a	0.876 a	0.594 a
CV (%)	7.666	3.718	1.803	2.322

At specific days after anthesis, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

Table 74a: Effect of variety on grain growth rate of wheat at day after anthesis (2014-15)

Variety	Grain growth rate (mg grain ⁻¹ day ⁻¹)			
	7-14 DAA	14-21 DAA	21-28 DAA	28-35 DAA
V ₁	2.119 a	1.714 a	0.749 a	0.503 a
V ₂	2.108 a	1.633 a	0.743 a	0.518 a
CV (%)	7.664	5.536	14.535	2.324

At specific days after anthesis, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

Table 74b: Effect of variety on grain growth rate of wheat at day after anthesis (2015-16)

Variety	Grain growth rate (mg grain ⁻¹ day ⁻¹)			
	7-14 DAA	14-21 DAA	21-28 DAA	28-35 DAA
V ₁	2.157 a	1.746 a	0.762 a	0.513 a
V ₂	2.146 a	1.663 a	0.756 a	0.528 a
CV (%)	7.666	3.718	1.803	2.322

At specific days after anthesis, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

Table 75a: Effect of nitrogen grain growth rate of wheat at day after anthesis (2014-15)

Nitrogen	Grain growth rate (mg grain ⁻¹ day ⁻¹)			
	7-14 DAA	14-21 DAA	21-28 DAA	28-35 DAA
N ₀	1.859 c	1.385 c	0.474 b	0.363 c
N ₁	2.165 b	1.694 b	0.793 a	0.527 b
N ₂	2.244 a	1.856 a	0.880 a	0.602 a
N ₃	2.186 ab	1.761 ab	0.835 a	0.551 ab
CV (%)	7.664	5.536	14.535	2.324

At specific days after anthesis, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

Table 75b: Effect of nitrogen grain growth rate of wheat at day after anthesis (2015-16)

Nitrogen	Grain growth rate (mg grain ⁻¹ day ⁻¹)			
	7-14 DAA	14-21 DAA	21-28 DAA	28-35 DAA
N ₀	1.892 c	1.410 c	0.483 b	0.370 c
N ₁	2.204 b	1.725 b	0.808 a	0.537 b
N ₂	2.285 a	1.889 a	0.896 a	0.613 a
N ₃	2.225 ab	1.793 ab	0.850 a	0.562 ab
CV (%)	7.666	3.718	1.803	2.322

At specific days after anthesis, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

Table 76a: Interaction effect of irrigation and nitrogen on grain growth rate of wheat at day after anthesis (2014-15)

Interaction (Irrigation × Nitrogen)	Grain growth rate (mg grain ⁻¹ day ⁻¹)			
	7-14 DAA	14-21 DAA	21-28 DAA	28-35 DAA
I ₀ N ₀	1.764 m	1.316 j	0.352 i	0.283 i
I ₀ N ₁	2.044 i	1.493 g-i	0.586 g	0.370 h
I ₀ N ₂	2.102 gh	1.578 fg	0.739 e	0.522 f
I ₀ N ₃	2.057 hi	1.525 f-h	0.671 f	0.439 g
I ₁ N ₀	1.829 l	1.373 ij	0.420 h	0.384 h
I ₁ N ₁	2.137 fg	1.635 ef	0.770 e	0.530 ef
I ₁ N ₂	2.239 cd	1.819 cd	0.829 d	0.588 b-d
I ₁ N ₃	2.185 ef	1.751 de	0.756 e	0.545 d-f
I ₂ N ₀	1.891 k	1.411 h-j	0.546 g	0.386 h
I ₂ N ₁	2.208 de	1.756 de	0.900 c	0.572 c-e
I ₂ N ₂	2.303 ab	1.957 ab	0.961 ab	0.631 ab
I ₂ N ₃	2.234 c-e	1.764 c-e	0.961 ab	0.590 bc
I ₃ N ₀	1.953 j	1.439 h-j	0.578 g	0.398 gh
I ₃ N ₁	2.270 bc	1.893 bc	0.918 bc	0.637 a
I ₃ N ₂	2.334 a	2.069 a	0.993 a	0.667 a
I ₃ N ₃	2.272 bc	2.004 ab	0.951 ab	0.629 ab
CV (%)	7.664	5.536	14.535	2.324

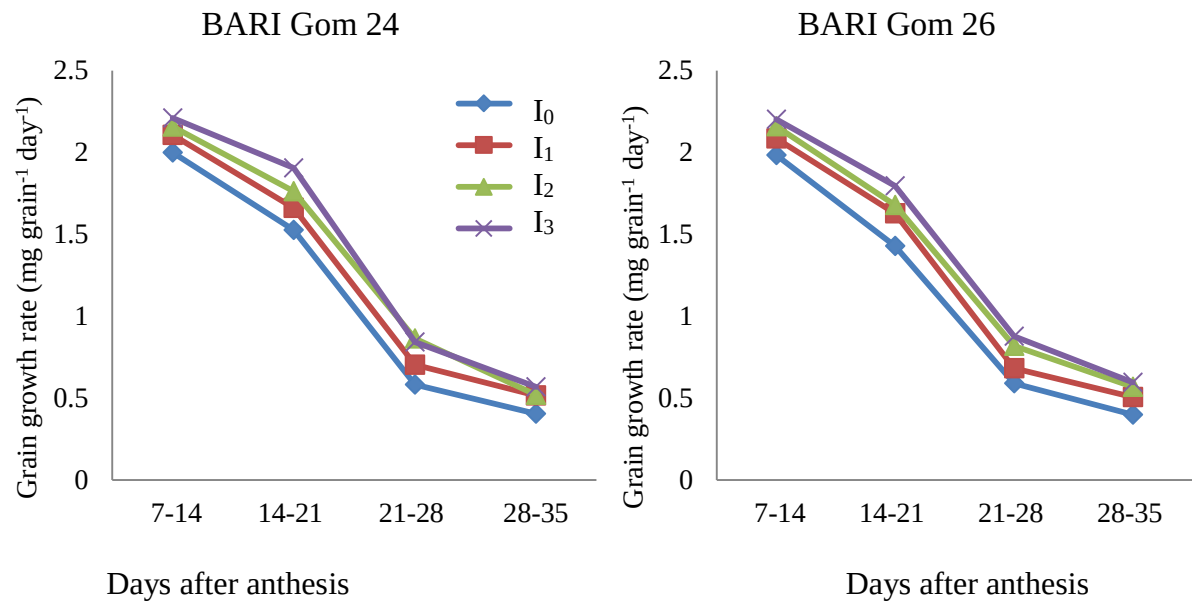
At specific days after anthesis, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

Table 76b: Interaction effect of irrigation and nitrogen on grain growth rate of wheat at day after anthesis (2015-16)

Interaction (Irrigation × Nitrogen)	Grain growth rate (mg grain ⁻¹ day ⁻¹)			
	7-14 DAA	14-21 DAA	21-28 DAA	28-35 DAA
I ₀ N ₀	1.796 m	1.340 j	0.358 i	0.288 i
I ₀ N ₁	2.080 i	1.520 g-i	0.596 g	0.377 h
I ₀ N ₂	2.140 gh	1.607 fg	0.752 e	0.532 f
I ₀ N ₃	2.094 hi	1.553 f-h	0.683 f	0.447 g
I ₁ N ₀	1.862 l	1.398 ij	0.428 h	0.391 h
I ₁ N ₁	2.176 fg	1.665 ef	0.784 e	0.540 ef
I ₁ N ₂	2.279 cd	1.853 cd	0.844 d	0.599 b-d
I ₁ N ₃	2.220 ef	1.783 de	0.770 e	0.556 d-f
I ₂ N ₀	1.925 k	1.437 h-j	0.556 g	0.393 h
I ₂ N ₁	2.248 de	1.787 de	0.916 c	0.583 c-e
I ₂ N ₂	2.344 ab	1.992 ab	0.978 ab	0.643 ab
I ₂ N ₃	2.274 c-e	1.796 c-e	0.978 ab	0.602 bc
I ₃ N ₀	1.988 j	1.466 h-j	0.589 g	0.406 gh
I ₃ N ₁	2.311 bc	1.928 bc	0.935 bc	0.649 a
I ₃ N ₂	2.376 a	2.106 a	1.010 a	0.680 a
I ₃ N ₃	2.313 bc	2.041 ab	0.968 ab	0.641 ab
CV (%)	7.666	3.718	1.803	2.322

At specific days after anthesis, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

a



b

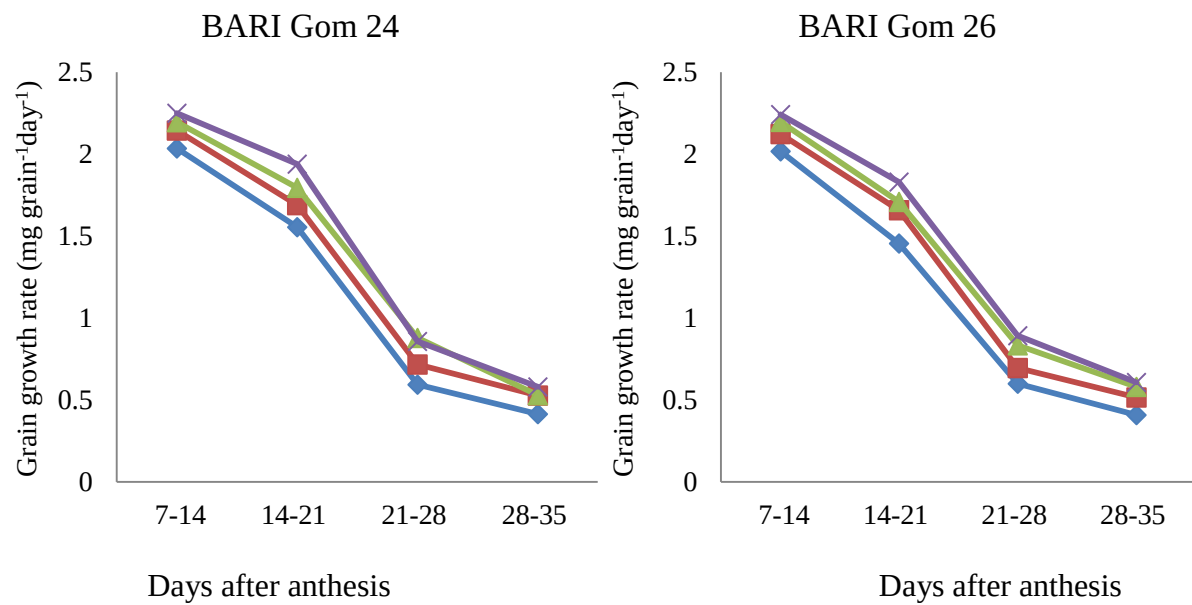


Fig. 31 Effect of irrigation on grain growth rate at different days after anthesis in 2014-15(a) and 2015-16(b)

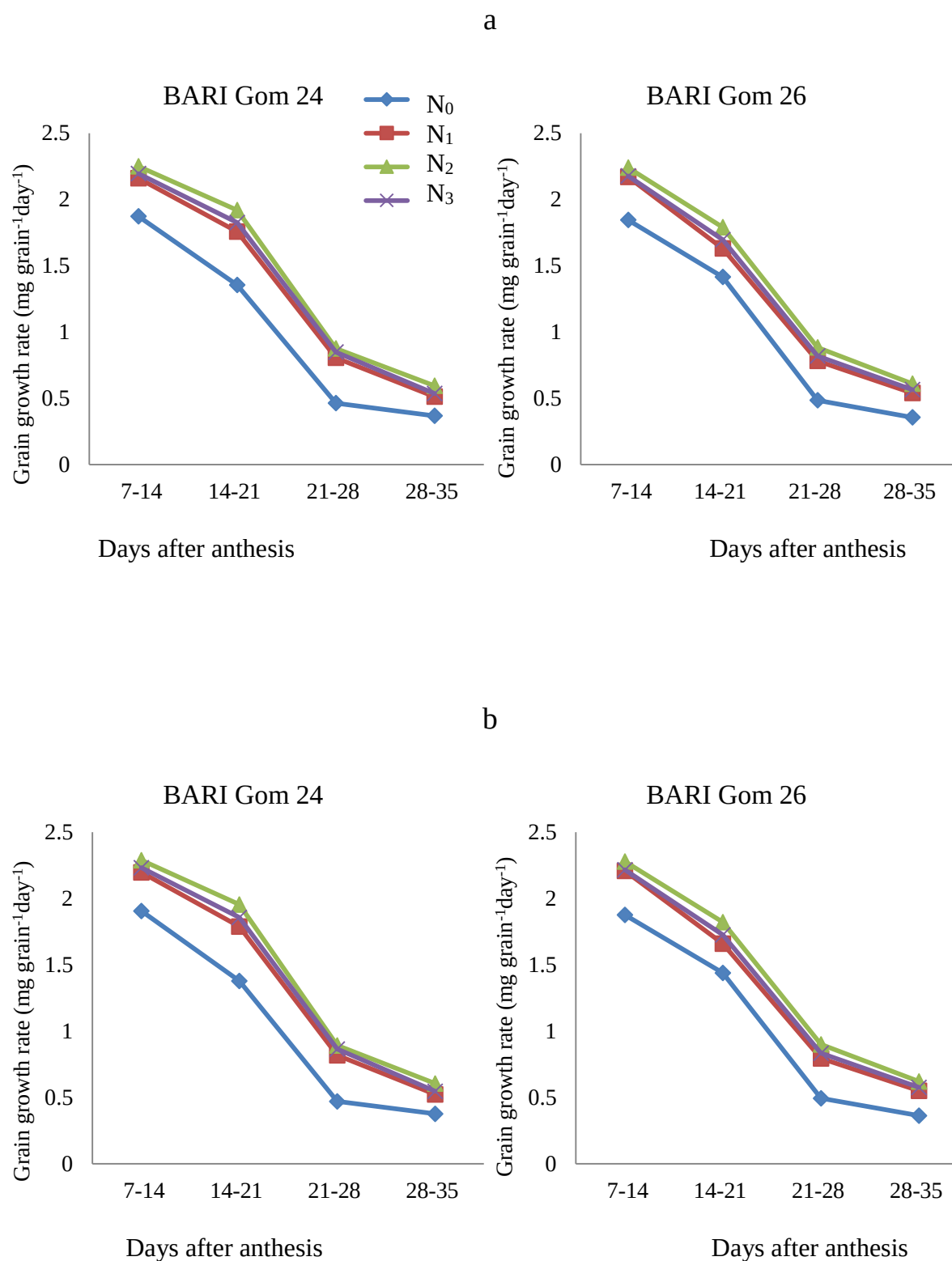


Fig. 32 Effect of nitrogen on grain growth rate at different days after anthesis in 2014-15(a) and 2015-16(b)

4.7. Yield and yield contributing characters

4.7.1. Plant height

Irrigation treatments had significant effect on plant height in both the years and are presented in Table 77a for first year (2014-15) and in Table 77b for second year (2015-16). Plant height is an important morphological character directly linked with the productive potential of plant in terms of grain yield. The tallest plant was produced by three irrigations (I_3) which was statistically identical to two irrigations (I_2) and the lowest plant height was obtained in rain-fed (I_0) condition in both the growing seasons. Wu *et al.* (2011) reported plant height increased with increasing number of irrigations. Similar result was reported in wheat by separate researchers (Rahman *et al.*, 2001, Pandit *et al.* 2001, Ali and Amin 2007, Islam *et al.*, 2011 and Sarker *et al.*, 2015). Khan *et al.* (2009) reported that plant height was positively and significantly associated with all morphological traits at the genetic level. Basunia (2000) stated that three irrigated plant produced tallest plant compared to others. This result also supported by many authors (Pandit *et al.*, 2001, Abodorrahmani *et al.*, 2005 and Sher and Parvender 2006).

Plant height did not show statistically significant variation due to variety in both the years and are given in Table 78a for first year (2014-15) and in Table 78b for second year (2015-16). Between the two varieties, higher plant height was observed in BARI Gom 24 than BARI Gom 26 in the present investigation.

Plant height was significantly influenced by split applications of nitrogen in both the years and is shown in Table 79a for first year (2014-15) and in Table 79b for second year (2015-16). The tallest plant was produced by three split (N_2) applications of nitrogen which was statistically identical with four split (N_3) applications of nitrogen and the lowest value was found in control (N_0) in both the years (99a and 99b). Similar result was reported in wheat by separate researchers (Naveed *et al.*, 2013 and Sarker *et al.*, 2015). Ananda (2004) reported that split application of N as half basal +one fourth at 30 DAS + one fourth at 60 DAS recorded maximum plant height of wheat. Wagan *et al.* (2002) reported that nitrogen applied in three split doses significantly increased plant height. Raigar and Pareek (2006) also found similar results in their experiment.

Different treatment combinations of irrigation and nitrogen had significant influence on plant height in both the growing seasons is given in Table 80a for first year (2014-15) and Table 80b for second year (2015-16). The highest plant height was recorded by the treatment

combination of three irrigations (I_3) $\times$ three splits (N_2) application of nitrogen followed by $I_3 \times N_3$ and $I_3 \times N_1$ and the lowest value was obtained in rain-fed (I_0) $\times$ control (N_0) in both the years.

4.7.2. Effective tillers plant⁻¹

Irrigation treatments significantly influenced the production of effective tillers plant⁻¹ compared to the rain-fed in both the growing seasons and are presented in Table 77a for first year (2014-15) and in Table 77b for second year (2015-16). The highest number of tillers plant⁻¹ was obtained from the crop receiving three irrigations which was statistically similar with two (I_2) irrigations and the lowest value was recorded from the rain-fed (I_0) crops in both the years. Irrigation had significant effect on number of effective tillers plant⁻¹ in wheat (Sarker and Paul 1997, Rahman *et al.*, 2001 and Afzal *et al.*, 2006). The response of effective tillers plant⁻¹ produced with increased irrigation frequencies was progressive in wheat (Rahman *et al.*, 2001 and Rafiq *et al.*, 2005).

Effect tillers plant⁻¹ varied significantly due to variety in both the years and are given in Table 78a and for first year (2014-15) and in Table 78b for second year (2015-16). Significantly higher effective tillers plant⁻¹ was produced by BARI Gom 26 in both the years.

Effective tillers plant⁻¹ was significantly influenced by split applications of nitrogen in both the years and are shown in Table 79a for first year (2014-15) and in Table 79b for second year (2015-16). Effective tillers are the key component of grain yield in wheat crop. More effective tillers were produced by applying high nitrogen fertilizer. The highest effective tillers were produced by three split (N_2) applications of nitrogen which was at par with basal (N_1) applications of nitrogen and the lowest value was found in control (N_0) in both the years. The reason of increased number of productive tillers in plots receiving split application of nitrogen may be due to sufficient availability of nitrogen during tillering stage. On the contrary, plots with control or received all the nitrogen at sowing resulted in less number of tillers due to less availability of the nutrient. Bulk nitrogen application at sowing may have resulted in leaching or volatilization of the nutrient that subsequently resulted in significantly lower number of productive tillers. Similar result was reported by Naveed (2013). Njuguna *et al.* (2010) concluded that nitrogen application increased the number of fertile tillers and grain yield. Abedi *et al.* (2011) showed that no N application decreased the number of productive tillers.

Different treatment combinations of irrigation and nitrogen had significant influence on effective tillers plant⁻¹ in both the growing seasons and are given in Table 80a for first year (2014-15) and in Table 80b for second year (2015-16). The highest effective tillers plant⁻¹ was produced by the treatment combination of three irrigations (I₃) × three splits (N₂) application of nitrogen followed by I₃ × N₁ and I₂ × N₂ and the lowest value was obtained in rain-fed (I₀) × control (N₀) in both the years.

4.7.3. Spike length

Spike length was significantly influenced by different irrigation levels in both the years and is presented in Table 77a for first year (2014-15) and in Table 77b for second year (2015-16). The highest value of spike length was produced by three irrigations (I₃) which was statistically similar with two (I₂) irrigations and the lowest value was found in control (I₀) in both the years. That is, the decrease in spike length due to rain-fed condition was noticed in the present study. Similar results were reported in wheat by Razi-us Shams (2001), Haider (2002) and Rahman (2004) and Sarker *et al.* (2015) and in barley by Bahadur (2008). Mishra and Padmakar (2010) reported that progressive increase in number of irrigations from 1 to 4 increased spike length while three and four irrigations were found statistically at par with each other. Ali and Amin (2007) showed that significant effects on spike length due to different levels of irrigation and also observed that two irrigations at 21 and 45 DAS significantly enhanced the yield and yield attributes of wheat. Alsohaibani (2007) observed that irrigation level had highly significant effect on spike length of wheat. Hefni *et al.* (2000) reported that irrigation plays a positive role in increasing spike length and they also reported that spike length reduced significantly if irrigation is stopped at tillering and booting stages of wheat.

Variety had no significant effect on spike length in both the growing seasons are given in Table 78a for first year (2014-15) and Table 78b for second year (2015-16). Between the two varieties, BARI Gom 24 had higher spike length than BARI Gom 26 in both the years.

The effects of split applications of nitrogen on spike length in both the years and are shown in Table 79a for first year (2014-15) and in Table 79b for second year (2015-16). The highest spike length was recorded in three split (N₂) applications of nitrogen which was statistically identical with four split (N₃) and basal (N₁) applications of nitrogen and the lowest value of spike length was found in control (N₀) in both the years. Nitrogen nutrient took part in spike formation as well as spike elongation and for this reason spike length increased with the

increase of N- fertilization. Oad *et al.* (2007) reported that split application of N significantly produced lengthy spikes. Upadhyay and tiwari (1996) also found similar results in their study with wheat varieties.

Spike length showed statistically significant variation by the interaction of irrigation and nitrogen in both the years and is given in Table 80a for first year (2014-15) and in Table 80b for second year (2015-16). The highest spike length was produced by the treatment combination of three irrigations (I_3) $\times$ three split (N_2) applications of nitrogen fertilizer which was statistically similar to three irrigations (I_3) $\times$ four split (N_3) applications of nitrogen and the lowest spike length was observed in rain-fed (I_0) $\times$ control (N_0) in both the years.

4.7.4. Extrusion Length

Irrigation levels showed significant effect on extrusion length in both the growing seasons are presented in Table 77a for first year (2014-15) and Table 77b for second year (2015-16). The wheat crops grown with three irrigations (I_3) gave the highest extrusion length which was statistically identical with two (I_2) irrigations and the lowest value was obtained in rain-fed (I_0) condition in both the years. Similar result was reported in barley by Bahadur (2008). This findings was supported by Mollah and Paul (2011) obtained that the highest and the lowest extrusion length were in the I_2 (40 mm water as three times) and I_0 (no irrigation) treatments respectively in barley.

Extrusion length did not show statistically significant variation due to variety in both the years are given in Table 78a for first year (2014-15) and in Table 78b for second year (2015-16). Between the two varieties, higher extrusion length was produced by the variety BARI Gom 24 in both the years.

The effects of nitrogen on extrusion length in both the years are shown in Table 79a for first year (2014-15) and in Table 79b for second year (2015-16). The highest extrusion length was observed in three split (N_2) applications of nitrogen which was statistically similar with four split (N_3) and basal (N_1) applications of nitrogen and the lowest value of extrusion length was found in control (N_0) in both the years.

Different treatment combinations of irrigation and nitrogen had significant influence on extrusion length in both the growing seasons and are given in Table 80a for first year (2014-15) and in Table 80b for second year (2015-16). The highest extrusion length was recorded by the treatment combination of three irrigations (I_3) $\times$ three splits (N_2) application of

nitrogen followed by $I_3 \times N_3$ and $I_3 \times N_1$ and the lowest value was obtained in rain-fed (I_0) $\times$ control (N_0) in both the years.

4.7.5. Fertile spikelets spike⁻¹

Fertile spikelets spike⁻¹ was significantly influenced by irrigation treatments in both the years and are presented in Table 77a for first year (2014-15) and Table 77b for second year (2015-16) respectively. The highest fertile spikelets spike⁻¹ was produced in three irrigations (I_3) which was statistically similar with two (I_2) irrigations and lowest value was observed in rain-fed (I_0) in both the growing seasons. Ali and Amin (2007) observed that significant effects on number of fertile spikelets spike⁻¹ due to different levels of irrigation in wheat. Similar results were also found by Mollah (2007), Bahadur (2008), Mollah and Paul (2011) in barley and Rahman *et al.* (2001), Rahman (2004), Rafiq *et al.* (2005) in wheat.

There was no significant difference in fertile spikelets spike⁻¹ due to variety in both the years are given in Table 78a for first year (2014-15) and in Table 78b for second year (2015-16). Between the two varieties, the higher fertile spikelets spike⁻¹ was recorded in BARI Gom 24 in both the years.

There had a marked influence on fertile spikelets spike⁻¹ by splits application of nitrogen in both the years and are presented in Table 79a for first year (2014-15) and in Table 79b for second year (2015-16). The highest fertile spikelets spike⁻¹ was observed in three split (N_2) applications of nitrogen which was at par with four split (N_3) applications of nitrogen followed by basal (N_1) application of nitrogen and the lowest value was found in control (N_0) in both the growing seasons. N nutrient encouraged fertile spikelets spike⁻¹ production and for the reason fertile spikelets spike⁻¹ increased with the increase of N- fertilization. Deshmukh *et al.* (2003) reported that nitrogen application in three splits at sowing, crown root initiation and joining produced higher number of spikelets spike⁻¹ compared to other splits. Das (2002) found that fertile spikelets spike⁻¹ increased with the increasing rate of nitrogen. Mozumder (2001) reported that number of fertile spikelets spike⁻¹ increased with the gradual increase of nitrogen. Upadhyay and Tiwari (1996) reported that increased fertile spikelets spike⁻¹ in high dose of nitrogen compared with lower dose.

Fertile spikelets spike⁻¹ showed statistically significant variation by the interaction of irrigation and nitrogen in both the years and is presented in Table 80a for first year (2014-15) and in Table 80b for second year (2015-16). The highest fertile spikelets spike⁻¹ was produced by the treatment combination of three irrigations (I_3) $\times$ three splits (N_2) application

which was statistically identical to three irrigations (I_3) $\times$ four splits (N_3) application of nitrogen and the lowest fertile spikelets spike⁻¹ was observed in rain-fed (I_0) $\times$ control (N_0) in both the years.

4.7.6. Infertile spikelets spike⁻¹

Infertile spikelets spike⁻¹ was affected significantly due to different irrigations in both the years and are presented in Table 77a for first year (2014-15) and in Table 77b for second year (2015-16). It was observed that increased irrigation levels significantly decreased the infertile spikelets spike⁻¹. The highest infertile spikelets spike⁻¹ was obtained in rain-fed (I_0) crops followed by one (I_1) and two (I_2) irrigated plants. The lowest infertile spikelets spike⁻¹ was obtained in three (I_3) irrigated crops in both the trails. This result was in agreement with Bahadur (2008) in barley.

Infertile spikelets spike⁻¹ did not show statistically significant variation due to variety in both the years are given in Table 78a for first year (2014-15) and in Table 78b for second year (2015-16). Between the two varieties, the higher infertile spikelets spike⁻¹ was recorded in BARI Gom 24 in both the years.

Infertile spikelets spike⁻¹ was significantly influenced by split applications of nitrogen in both the trails and is presented in Table 79a for first year (2014-15) and in Table 79b for second year (2015-16). Infertile spikelets spike⁻¹ decreased when the amount of nitrogenous fertilizer application increased. The highest infertile spikelets spike⁻¹ was recorded in control (N_0) followed by basal (N_1) and four split (N_3) applications of nitrogen and the lowest value was found in three split (N_2) applications of nitrogen in both the years. Similar results were also reported by Bahadur (2008) in barley.

The interaction effect of irrigation and nitrogen exhibited a significant variation in infertile spikelets spike⁻¹ in both the growing seasons and are shown in Table 80a for first year (2014-15) and Table 80b for second year (2015-16). The highest infertile spikelets spike⁻¹ was produced in the combination of rain-fed (I_0) $\times$ control (N_0) followed by $I_1 \times N_0$ and the lowest number was produced in two irrigation (I_2) $\times$ three splits (N_2) application of nitrogen in both the years.

4.7.7. 1000-grain weight

The effect of irrigation treatments on 1000-grain weight in both the years are presented in Table 77a for first year (2014-15) and in Table 77b for second year (2015-16). The irrigation levels had significant effect on 1000-grain weight in both the years and it was observed that

increasing irrigation level significantly increased 1000-grain weight. In the present study, three irrigated (I_3) plants were produced the highest 1000-grain weight which was statistically similar with two irrigated (I_2) plants followed by one irrigated (I_1) plants and the lowest grain weight was found in rain-fed (I_0) in both the years. Similar result was reported in wheat by Rahman and Paul 1998, Rahman *et al.*, 2001, Rahman 2004 and Rafiq *et al.*, 2005 and in barley by Afzal *et al.*, 2006 and Bahadur 2008. Kong *et al.* (2008) observed that irrigation at grain filling stage improved the 1000-grain weight of wheat. Mushtaq and Muhammad (2005) in their experiment found that 1000-grain weight was significantly higher under 4 irrigations applied at crown root + boot+ milk + grain development stages of wheat. Sher and Parvender (2006) found similar results with the present study. Mollah and Paul (2011) stated that I_2 (40 mm water as three times) irrigation produced the highest 1000-grain weight and the lowest was in the control in barley. These finding is corroborated with Rahman and Paul (1998) and Rahman *et al.* (2001) in wheat.

The effect of variety on 1000-grain weight was not significant in both the years are given in Table 78a for first year (2014-15) and in Table 78b for second year (2015-16). Significantly higher 1000-grain weight was produced by BARI Gom 24 (V_1) in both the growing seasons.

The effects of split application of nitrogen was found to be significant in respect of 1000-grain weight in both the growing seasons and are presented in Table 79a for first year (2014-15) and in Table 79b for second year (2015-16). Three split (N_2) applications of nitrogen was produced the highest 1000-grain weight which was statistically similar with four split (N_3) and basal (N_1) applications of nitrogen and the lowest value of 1000-grain weight was found in control (N_0) in both the years. Similar results were recorded in wheat by Rahman *et al.*, 2011 and Sarker *et al.*, 2015. Nitrogen produced heavy and plum grains and thus 1000-grain was increased (Rahman 2004). Deshmukh *et al.* (2003) reported that nitrogen application in three splits at sowing, crown root initiation and joining produced higher 1000-grain weight compared to other splits. Pandit *et al.* (2002) also reported similar findings in their study with wheat. Rahman *et al.* (2014) reported that nitrogen plays a vital role in grain growth and development.

1000-grain weight showed statistically significant variation by the interaction of irrigation and nitrogen in both the years and is given in Table 80a for first year (2014-15) and in Table 80b for second year (2015-16). The highest 1000-grain weight was produced by the treatment combination of three irrigations (I_3) $\times$ three splits (N_2) application of nitrogen which was also

statistically similar with $I_3 \times N_3$ treatments followed by $I_3 \times N_1$ and the lowest 1000-grain weight was produced in rain-fed (I_0) $\times$ control (N_0) in both the years.

4.7.8. Grain yield

The grain yield for the different irrigation schedules are shown in Table 77a for first year (2014-15) and in Table 77b for second year (2015-16). Irrigation treatments had significant effect on grain yield in both the years. The highest grain yield was produced by three irrigations (I_3) which was at par with two irrigations (I_2) followed by one irrigation (I_1) and the lowest grain yield was produced in rain-fed (I_0) condition in both the growing seasons. Yield reduced in wheat due to water shortage was attributed to reduced fertile tillers, fertile spikelets and number of grains and reduced individual grain weight. Water stress during meiosis in microspore mother cells of wheat induced male sterility which resulted in reduced grain yield (Lalonde *et al.*, 1997). Grain yield in wheat is the result of number of effective tillers, number of grains per spike and grain weight (Ahmad *et al.*, 1988). Assimilation and partitioning of photosynthates in relation to grain growth are therefore of vital importance. Responses to irrigation vary among the yield components because of the differences in soil water conditions during the growing season (Frederick and Camberato 1995b). Irrigation from the beginning of tillering to anthesis in this study resulted in the production of more number of effect spikes and higher grain yield. Matsunaka *et al.* (1992) also reported increased grain yield of wheat with the increase in number of effective spikes per unit area. Increase in grain yield with increasing frequency of irrigation has also been reported by Frizzone *et al.* (1996), Karim *et al.* (1997) and Gill and Singh (1999). Mushtaq and Muhammad (2005) reported that grain yield of wheat was significantly higher under 4 irrigations. Ali and Amin (2007) confirmed that grain yield was significantly higher at two irrigations compared to the other treatments. Jana and Mitra (2004) conducted experiments similar to this study and also reported that increase irrigation frequencies increased grain yield of wheat. Hefni *et al.* (2000) reported that irrigation plays a positive role in increasing grain yield. In the present study, grain yield was higher in the irrigated plants than in the rain-fed plants. Similar results were recorded in wheat by Razi-us Shams 2001, Rahman *et al.*, 2001, Pandit *et al.*, 2001, Rafiq *et al.*, 2005, Warraich *et al.*, 2007, Alsohaibani 2007 and Sarker *et al.*, 2015 and in barley by Nowak *et al.*, 2005, Afzal *et al.*, 2006, Mollah 2007, Naeem Sarwar *et al.*, 2010, Sana Ullah Baloch 2014, Shirazi *et al.*, 2014 and Atikullah *et al.*, 2014. Ngwako and Mashiqua (2013) stated that irrigation enhance grain yield by improving the growth of the crop and thus enabling it to intercept more photosynthetic radiation over

non-irrigated plants. These results substantiate findings of Kabir *et al.* (2009) who also noted similar effects of irrigation on grain yield while working on wheat. Wajid *et al.* (2002) reported that wheat crop produced highest grain yield by applying irrigation at all definable growth stages. Khan *et al.* (2007) stated that too early and late irrigation is harmful for the maximum return and the irrigation should be given at right time for maximum yield.

Grain yield did not show statistically significant variation due to variety in both the years and are given in Table 78a for first year (2014-15) and in Table 78b for second year (2015-16). Between the two varieties BARI Gom 24 produced higher grain yield than BARI Gom 26.

Grain yield of wheat was significantly affected by split applications of nitrogen in both the years and are presented in Table 79a for first year (2014-15) and in Table 79b for second year (2015-16). In this study, the highest grain yield was produced in three splits (N_2) which was statistically similar with four split (N_3) applications of nitrogen followed by basal (N_1) and the lowest grain yield was found in control (N_0) in both the years. Similar trend of the effect of nitrogen was observed in wheat (Awasthi and Bhan 1993, Pandit *et al.*, 2002, Ali *et al.*, 2005, Naveed *et al.*, 2013, Abdelraouf *et al.* (2013), Mandic *et al.*, 2014, Szmigiel *et al.*, 2014, Rahman *et al.*, 2014 Sarker *et al.*, 2015 and Inwati *et al.*, 2018). The data during both the years manifested that grain yield increased progressively with split application of nitrogen being maximum receiving larger quantity of nitrogen applied. It may be due to efficient utilization and arresting volatilization or leaching down of nitrogen. The reverse was true for either no nitrogen applied plots. The results regarding enhanced grain yield due to split application of nitrogen are ascertained by Abedi *et al.* (2011) who demonstrated that the amount of N fertilization before wheat planting was completely unnecessary and was likely to move beyond the root zone. Similar results were also reported by other researches (Lopez-Bellido *et al.*, 2005, Chen *et al.*, 2006, and Cui *et al.*, 2010). Woolfolk *et al.* (2002) who concluded that nitrogen application near flowering is effective to increase post-flowering nitrogen uptake, grain yield and grain protein content. Oad *et al.* (2007) confirmed that split application of N significantly produced maximum grain yield. Sarker *et al.* (1996), Deshmukh *et al.* (2003) and Raigar and Pareek (2006) also found similar results in their experiments with wheat.

Different treatment combinations of irrigation and nitrogen had significant influence on grain yield in both the growing seasons are presented in Table 80a for first year (2014-15) and in Table 80b for second year (2015-16). The highest grain yield was produced by the treatment combination of three irrigations (I_3) $\times$ three splits (N_2) application of nitrogen followed by I_3

$\times N_3$ and $I_2 \times N_2$ and the lowest value was obtained in rain-fed (I_0) $\times$ control (N_0) in both the years.

4.7.9. Straw yield

Straw yield was affected significantly due to different irrigation levels in both the years is presented in Table 77a for first year (2014-15) and Table 77b for second year (2015-16). It was observed that increased irrigation levels significantly increased straw yield. The highest straw yield was observed from three irrigations (I_3) which was statistically at par with two irrigations (I_2) and the lowest straw yield was found in rain-fed (I_0) condition followed by one irrigation (I_1) in both the trails. Similar result was reported in wheat by Yadav *et al.*, 2001, Rani *et al.*, 2000, Sher and Parvender 2006 and in barley Chaudhary and Sharma 2003, Baheri *et al.*, 2005, Bahadur 2008. Ali and Amin (2007) reported that straw yield was significantly higher at two irrigations compared to the other treatments. Jana and Mitra (2004) conducted experiments similar to this study and also reported that increase irrigation frequencies increased straw yield. Islam (2003) reported that straw yield of wheat increased when the crop was irrigated at different phenological stages which confirm the findings of the present study.

The difference in straw yield due to variety was not statistically significant in both the years are given in Table 78a for first year (2014-15) and in Table 78b for second year (2015-16). Between the two varieties, BARI Gom 24 produced higher straw yield than BARI Gom 26.

There had a marked influence on straw yield by different split applications of nitrogen in both the years and are presented in Table 79a for first year (2014-15) and in Table 79b for second year (2015-16). The highest straw yield was produced by three splits (N_2) application of nitrogen which was statistically identical with four split (N_3) applications of nitrogen followed by basal (N_1) application of nitrogen and the lowest straw yield was produced in control (N_0) in both the trails. Similar result was reported by Ali *et al.*, 2005, Afridi *et al.*, 2010, Sarker *et al.*, 2015. Raigar and Pareek (2006) noted that application of nitrogen in three split significantly increased straw yield in wheat. Deshmukh *et al.* (2003) and Pandit *et al.* (2002) also found similar findings in wheat which gave conformity at the present study. Increased straw yield was observed with increase of N-fertilizer. Similar results were observed in wheat (Dhuka *et al.*, 1992, Singh *et al.*, 1992, Awasthi and Bhan 1993, Singh and Singh 1995 and Singh *et al.*, 1996).

Straw yield showed statistically significant variations by the interaction of irrigation and nitrogen in both the years are given in Table 80a for first year (2014-15) and in Table 80b for second year (2015-16). The highest straw yield was produced by the treatment combination of three irrigations (I_3) $\times$ three splits (N_2) application followed by $I_2 \times N_2$ and $I_3 \times N_3$ and the lowest straw yield was observed in rain-fed (I_0) $\times$ control (N_0) in both the years.

4.7.10. Biological yield

Irrigation treatments significantly influenced the biological yield compared to the rain-fed (I_0) in both the years and are presented in Table 77a for first year (2014-15) and in Table 77b for second year (2015-16). The highest biological yield was obtained from the crop receiving three irrigations (I_3) which was at par with two irrigations (I_2) followed by one irrigation (I_1) and the lowest biological yield was produced in rain-fed (I_0) condition in both the growing seasons. Alsohaibani (2007) noted that higher biological yield of wheat with irrigated crops. Gupta *et al.* (2001) reported that biological yield decreased to a greater extent when water stress was imposed at the anthesis stage. Finding of Pandit *et al.* (2001) were also similar to the findings of the present study, where they found three times irrigation at crown root initiation, booting and early grain filling stages resulted in higher biological yield of wheat as against no irrigation.

The effects of variety on biological yield in both the years are shown in Table 78a for first year (2014-15) and in Table 78b for second year (2015-16). There was no significant effect on biological yield in different wheat variety in both the years. Between the two varieties, BARI Gom 24 produced higher biological yield than BARI Gom 26.

There was statistically significant effect of split applications of nitrogen on biological yield in both the growing seasons and are presented in Table 79a for first year (2014-15) and in Table 79b for second year (2015-16). The highest biological yield was produced in three split (N_2) applications of nitrogen which was a par with four split (N_3) applications of nitrogen followed by basal (N_1) application of nitrogen and the lowest yield was found in control (N_0) in both the years. The increase in biological yield was obtained by improved nitrogen use efficiency due to the increase in plant height and number of spikes m^{-2} .

Different treatment combinations of irrigation and nitrogen had significant influence on biological yield in both the growing seasons and are given in Table 80a for first year (2014-15) and in Table 80b for second year (2015-16). The highest biological yield was produced by the treatment combination of three irrigations (I_3) $\times$ three splits (N_2) application of

nitrogen followed by $I_2 \times N_2$ and $I_3 \times N_3$ and the lowest value was obtained in rain-fed (I_0) $\times$ control (N_0) in both the years.

4.7.11. Harvest index

Harvest index was affected significantly due to different irrigation levels in both the years and are presented in Table 77a for first year (2014-15) and in Table 77b for second year (2015-16). Harvest index is the proportion of commercial yield and biological yield. Harvest index is defined as the percentage grain in the total plant biomass. The ability of a cultivar to convert total dry matter into grain or economic yield is indicated by its harvest index value. It was observed that increased irrigation levels significantly increased harvest index. The highest harvest index was observed in three irrigations (I_3) which was statistically identical with two irrigations (I_2) followed by one irrigation (I_1) and the lowest harvest index was found in rain-fed (I_0) condition in both the trails. Similar result was observed by Rafiq *et al.* (2005), Baheri *et al.* (2005) and Xue *et al.* (2006), Warraich *et al.* (2007) and Sarker (2015). Ali and Amin (2007) showed that harvest index was significantly higher at two irrigations compared to the other treatments in wheat. Ngwako and Mashiqua (2013) stated that irrigation at all growth stages of crop plant increased harvest index over no irrigation treatment.

The difference in harvest index due to variety was not statistically significant in both the years are shown in Table 78a for first year (2014-15) and in Table 78b for second year (2015-16). Between the two varieties, higher harvest index was found in BARI Gom 24.

There had a marked influence on harvest index by different splits application of nitrogen in both the years and are presented in Table 79a for first year (2014-15) and in Table 79b for second year (2015-16). The highest harvest index was recorded in three splits (N_2) application which was statistically identical to four splits (N_3) application of nitrogen followed by basal (N_1) application of nitrogen and the lowest harvest index was found in control (N_0) in both the trails.

Harvest index showed statistically significant variation by the interaction of irrigation and nitrogen in both the years and are given in Table 80a for first year (2014-15) and in Table 80b for second year (2015-16). The highest harvest index was obtained in the treatment combination of three irrigations (I_3) $\times$ three splits (N_2) application of nitrogen followed by $I_3 \times N_3$ and $I_3 \times N_1$ and the lowest harvest index was observed in rain-fed (I_0) $\times$ control (N_0) in both the years.

Table 77a: Effect of irrigation on yield components and yield of wheat (2014-2015)

Irrigation	Plant height (cm)	Effective tillers plant ⁻¹	Spike length (cm)	Extrusion length (cm)	Fertile spikelets panicle ⁻¹	Infertile spikelets panicle ⁻¹	1000-grain weight (g)	grain yield (kg ha ⁻¹)	Straw yield (kg ha ⁻¹)	Biological yield (kg ha ⁻¹)	Harvest index
I ₀	85.327 b	2.033 c	11.514 c	31.896 b	14.758 c	3.875 a	44.377 c	2288.937 c	3919.973 c	6208.909 c	36.751 b
I ₁	88.663 b	2.608 bc	12.715 bc	33.462 b	15.792 bc	2.742 b	47.288 bc	2762.668 b	4460.606 b	7223.274 b	38.094 b
I ₂	95.261 a	3.167 ab	14.011 ab	35.334 ab	17.392 ab	2.475 b	49.863 ab	3835.018 ab	5737.751 ab	9572.769 ab	39.718 ab
I ₃	98.950 a	3.667 a	14.737 a	37.449 a	18.417 a	2.442 b	52.281 a	4076.721 a	5845.911 a	9922.632 a	40.763 a
CV (%)	5.435	7.838	5.562	8.915	11.859	16.459	2.759	4.130	8.046	5.798	4.343

In a column, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

Table 77b: Effect of irrigation on yield components and yield of wheat (2015-2016)

Irrigation	Plant height (cm)	Effective tillers plant ⁻¹	Spike length (cm)	Extrusion length (cm)	Fertile spikelets panicle ⁻¹	Infertile spikelets panicle ⁻¹	1000-grain weight (g)	grain yield (kg ha ⁻¹)	Straw yield (kg ha ⁻¹)	Biological yield (kg ha ⁻¹)	Harvest index
I ₀	87.642 b	2.100 c	12.073 c	32.470 b	15.479 b	3.567 a	44.768 c	2385.345 c	3944.944 c	6330.289 c	37.565 b
I ₁	91.099 b	2.675 bc	13.334 bc	34.032 b	16.600 bc	2.517 b	47.700 bc	2878.682 b	4479.959 b	7358.641 b	38.964 b
I ₂	97.862 a	3.233 ab	14.698 ab	35.938 ab	18.267 ab	2.233 b	50.301 ab	3974.481 ab	5750.056 ab	9724.867 ab	40.525 ab
I ₃	101.638 a	3.733 a	15.459 a	38.091 a	19.346 a	2.042 b	52.742 a	4221.130 a	5851.997 a	10073.130 a	41.580 a
CV (%)	5.432	7.798	5.579	8.916	12.097	17.808	2.376	4.133	8.040	5.754	4.286

In a column, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

Table 78a: Effect of variety on yield components and yield of wheat (2014-2015)

Variety	Plant height (cm)	Effective tillers plant ⁻¹	Spike length (cm)	Extrusion length (cm)	Fertile spikelets panicle ⁻¹	Infertile spikelets panicle ⁻¹	1000-grain weight (g)	grain yield (kg ha ⁻¹)	Straw yield (kg ha ⁻¹)	Biological yield (kg ha ⁻¹)	Harvest index
V ₁	92.128 a	2.425 b	13.338 a	35.571 a	16.833 a	3.046 a	51.214 a	3256.264 a	4993.198 a	8249.462 a	38.938 a
V ₂	91.973 a	3.313 a	13.150 a	33.499 a	16.346 a	2.721 a	45.691 b	3225.408 a	4988.922 a	8214.330 a	38.725 a
CV (%)	5.435	7.838	5.562	8.915	11.859	16.459	2.759	4.130	8.046	5.798	4.343

In a column, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

Table 78b: Effect of variety on yield components and yield of wheat (2015-2016)

Variety	Plant height (cm)	Effective tillers plant ⁻¹	Spike length (cm)	Extrusion length (cm)	Fertile spikelets panicle ⁻¹	Infertile spikelets panicle ⁻¹	1000-grain weight (g)	grain yield (kg ha ⁻¹)	Straw yield (kg ha ⁻¹)	Biological yield (kg ha ⁻¹)	Harvest index
V ₁	94.640 a	2.492 b	13.990 a	36.186 a	17.688 a	2.788 a	51.664 a	3381.056 a	5008.944 a	8390.000 a	39.766 a
V ₂	94.480 a	3.379 a	13.793 a	34.079 a	17.158 a	2.392 a	46.092 b	3348.927 a	5004.534 a	8353.462 a	39.551 a
CV (%)	5.432	7.798	5.579	8.916	12.097	17.808	2.376	4.133	8.040	5.754	4.286

In a column, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

Table 79a: Effect of nitrogen on yield components and yield of wheat (2014-2015)

Nitrogen	Plant height (cm)	Effective tillers plant ⁻¹	Spike length (cm)	Extrusion length (cm)	Fertile spikelets panicle ⁻¹	Infertile spikelets panicle ⁻¹	1000-grain weight (g)	grain yield (kg ha ⁻¹)	Straw yield (kg ha ⁻¹)	Biological yield (kg ha ⁻¹)	Harvest index
N ₀	81.748 c	1.408 c	9.969 b	26.270 b	10.958 c	4.325 a	41.575 c	2281.756 c	4102.838 c	6384.593 c	35.618 c
N ₁	93.173 b	3.300 ab	13.894 a	36.343 a	17.742 b	2.525 b	49.645 b	3418.171 bc	5182.434 bc	8600.604 bc	39.404 bc
N ₂	97.858 a	3.683 a	14.738 a	38.184 a	19.008 a	2.308 b	51.800 a	3690.199 a	5389.998 a	9080.197 a	40.324 a
N ₃	95.422 ab	3.083 b	14.376 a	37.343 a	18.650 ab	2.375 b	50.788 ab	3573.219 ab	5288.971 ab	8862.190 ab	39.980 ab
CV (%)	5.435	7.838	5.562	8.915	11.859	16.459	2.759	4.130	8.046	5.798	4.343

In a column, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

Table 79b: Effect of nitrogen on yield components and yield of wheat (2015-2016)

Nitrogen	Plant height (cm)	Effective tillers plant ⁻¹	Spike length (cm)	Extrusion length (cm)	Fertile spikelets panicle ⁻¹	Infertile spikelets panicle ⁻¹	1000-grain weight (g)	grain yield (kg ha ⁻¹)	Straw yield (kg ha ⁻¹)	Biological yield (kg ha ⁻¹)	Harvest index
N ₀	83.977 c	1.475 c	10.455 b	26.724 b	11.504 c	3.950 a	41.941 c	2369.852 c	4116.411 c	6486.263 c	36.418 c
N ₁	95.714 b	3.367 ab	14.573 a	36.973 a	18.642 b	2.325 b	50.081 bc	3548.907 bc	5198.535 bc	8747.441 bc	40.237 bc
N ₂	100.526 a	3.75 a	15.458 a	38.844 a	19.963 a	2.083 b	52.255 a	3831.357 a	5406.668 a	9238.025 a	41.163 a
N ₃	98.024 ab	3.15 b	15.078 a	37.989 a	19.583 ab	2.000 b	51.235 ab	3709.852 ab	5305.343 ab	9015.195 ab	40.817 a
CV (%)	5.432	7.798	5.579	8.916	12.097	17.808	2.376	4.133	8.040	5.754	4.286

In a column, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

Table 80a: Interaction effect of irrigation and nitrogen on yield components and yield of wheat (2014-2015)

Interaction (Irrigation × Nitrogen)	Plant height (cm)	Effective tillers plant ⁻¹	Spike length (cm)	Extrusion length (cm)	Fertile spikelets panicle ⁻¹	Infertile spikelets panicle ⁻¹	1000-grain weight (g)	grain yield (kg ha ⁻¹)	Straw yield (kg ha ⁻¹)	Biological yield (kg ha ⁻¹)	Harvest index
I ₀ N ₀	76.410 n	1.133 i	8.670 l	25.071 g	9.100 h	5.100 a	36.333 g	1855.046 n	3614.730 h	5469.776 l	33.916 k
I ₀ N ₁	86.255 k	2.367 d-i	11.963 h	33.540 f	16.000 e	3.867 bc	45.597 d-f	2352.809 l	3985.832 g	6338.641 jk	37.123 ij
I ₀ N ₂	90.217 gh	2.533 d-h	12.930 f	34.796 ef	17.100 de	3.233 c-e	48.035 b-e	2512.489 j	4049.948 g	6562.438 hi	38.290 f-h
I ₀ N ₃	88.427 ij	2.100 e-i	12.493 g	34.177 ef	16.833 de	3.300 cd	47.542 b-e	2435.402 k	4029.380 g	6464.782 ij	37.677 g-i
I ₁ N ₀	79.020 m	1.367 hi	9.492 k	25.524 g	10.067 gh	4.667 ab	39.933 fg	2153.194 m	4006.052 g	6159.246 k	34.973 k
I ₁ N ₁	89.827 hi	3.000 b-f	13.440 e	35.231 d-f	17.300 de	1.833 f	49.317 a-e	2836.048 h	4510.304 e	7346.351 fg	38.609 e-g
I ₁ N ₂	94.175 f	3.333 b-e	14.248 d	37.006 c-e	18.067 b-d	2.467 d-f	50.158 a-e	3094.872 f	4740.252 d	7835.124 e	39.506 de
I ₁ N ₃	91.632 g	2.733 c-g	13.680 e	36.085 c-f	17.733 c-e	2.000 f	49.742 a-e	2966.561 g	4585.815 de	7552.376 f	39.287 d-f
I ₂ N ₀	84.622 l	1.467 g-i	10.507 j	26.562 g	11.833 fg	4.267 a-c	44.258 ef	2442.077 k	4288.941 f	6731.018 h	36.286 j
I ₂ N ₁	96.320 e	3.633 a-d	14.647 c	37.339 c-e	18.467 b-d	2.067 ef	50.595 a-e	4110.728 e	6078.945 c	10189.670 d	40.345 cd
I ₂ N ₂	101.398 bc	4.133 ab	15.575 b	39.209 a-c	19.833 ab	1.600 f	52.972 a-c	4473.911 c	6361.412 ab	10835.320 b	41.293 a-c
I ₂ N ₃	98.705 d	3.433 a-e	15.317 b	38.224 b-d	19.433 a-c	1.967 f	51.628 a-d	4313.357 d	6221.706 a-c	10535.060 c	40.947 bc
I ₃ N ₀	86.940 jk	1.667 f-i	11.207 i	27.923 g	12.833 f	3.267 cd	45.777 c-f	2676.706 l	4 501.628 e	7178.334 g	37.296 h-j
I ₃ N ₁	100.292 c	4.200 ab	15.527 b	39.264 a-c	19.200 a-c	2.333 d-f	53.073 ab	4373.098 d	6154.654 bc	10527.750 c	41.540 ab
I ₃ N ₂	105.642 a	4.733 a	16.198 a	41.724 a	21.033 a	1.933 f	56.035 a	4679.524 a	6408.379 a	11087.900 a	42.207 a
I ₃ N ₃	102.925 b	4.067 a-c	16.015 a	40.886 ab	20.600 a	2.233 d-f	54.240 ab	4577.554 b	6318.984 ab	10896.540 ab	42.010 ab
CV (%)	5.435	7.838	5.562	8.915	11.859	16.459	2.759	4.130	8.046	5.798	4.343

In a column, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

Table 80b: Interaction effect of irrigation and nitrogen on yield components and yield of wheat (2015-2016)

Interaction (Irrigation × Nitrogen)	Plant height (cm)	Effective tillers plant ⁻¹	Spike length (cm)	Extrusion length (cm)	Fertile spikelets panicle ⁻¹	Infertile spikelets panicle ⁻¹	1000-grain weight (g)	grain yield (kg ha ⁻¹)	Straw yield (kg ha ⁻¹)	Biological yield (kg ha ⁻¹)	Harvest index
I ₀ N ₀	78.485 n	1.200 i	9.088 l	25.522 g	9.517 h	4.633 a	36.653 g	1933.180 n	3637.757 h	5570.937 l	34.702 k
I ₀ N ₁	88.595 k	2.433 d-i	12.547 h	34.143 f	16.800 e	3.533 a-c	45.998 d-f	2451.908 l	4011.223 g	6463.131 jk	37.942 ij
I ₀ N ₂	92.663 gh	2.600 d-h	13.558 f	35.422 ef	17.933 de	2.967 c-f	48.458 b-e	2618.314 j	4075.748 g	6694.062 hi	39.118 f-h
I ₀ N ₃	90.825 ij	2.167 e-i	13.100 g	34.792 ef	17.667 de	3.133 b-d	47.962 b-e	2537.980 k	4055.049 g	6593.028 ij	38.500 g-i
I ₁ N ₀	81.190 m	1.433 hi	9.952 k	25.958 g	10.600 gh	4.267 ab	40.283 fg	2243.613 m	4023.433 g	6267.047 k	35.815 k
I ₁ N ₁	92.295 hi	3.067 b-f	14.095 e	35.832 d-f	18.167 de	1.733 g	49.745 a-e	2955.143 h	4529.873 e	7485.015 fg	39.484 e-g
I ₁ N ₂	96.762 f	3.400 b-e	14.943 d	37.637 c-e	19.000 b-d	2.267 d-g	50.597 a-e	3224.835 f	4760.819 d	7985.654 e	40.389 de
I ₁ N ₃	94.150 g	2.800 c-g	14.347 e	36.700 c-f	18.633 c-e	1.800 fg	50.177 a-e	3091.137 g	4605.712 de	7696.849 f	40.168 d-f
I ₂ N ₀	86.932 l	1.533 g-i	11.023 j	27.015 g	12.433 fg	3.900 a-c	44.648 ef	2531.094 k	4298.139 f	6829.233 h	37.067 j
I ₂ N ₁	98.950 e	3.700 a-d	15.365 c	37.978 c-e	19.400 b-d	1.900 e-g	51.040 a-e	4260.570 e	6091.982 c	10352.550 d	41.158 cd
I ₂ N ₂	104.167 bc	4.200 ab	16.338 b	39.880 a-c	20.833 ab	1.300 g	53.435 a-c	4636.992 c	6375.055 ab	11012.050 b	42.111 a-c
I ₂ N ₃	101.400 d	3.500 a-e	16.067 b	38.878 b-d	20.400 a-c	1.767 g	52.082 a-d	4470.586 d	6235.049 a-c	10705.630 c	41.764 bc
I ₃ N ₀	89.300 jk	1.733 f-i	11.758 i	28.402 g	13.467 f	3.000 c-e	46.180 c-f	2771.522 i	4506.315 ef	7277.837 g	38.089 h-j
I ₃ N ₁	103.017 c	4.267 ab	16.285 b	39.937 a-c	20.200 a-c	2.133 d-g	53.540 a-c	4528.006 d	6161.062 bc	10689.070 c	42.363 ab
I ₃ N ₂	108.512 a	4.800 a	16.993 a	42.438 a	22.083 a	1.733 g	56.528 a	4845.286 a	6415.051 a	11260.340 a	43.032 a
I ₃ N ₃	105.722 b	4.133 a-c	16.798 a	41.587 ab	21.633 a	1.367 g	54.718 ab	4739.704 b	6325.562 ab	11065.270 ab	42.835 ab
CV (%)	5.432	7.798	5.579	8.916	12.097	17.808	2.376	4.133	8.040	5.754	4.286

In a column, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

4.8. Correlation coefficient between yield and yield components

4.8.1. Effect of irrigation

Simple correlation co-efficient between yield and yield components of wheat as influenced by irrigation are shown in Tables 81, 82, 83 and 84.

4.8.1.1. Rain-fed condition

In the rain-fed wheat crops (I_0) plant height was positively correlated with effective tillers plant⁻¹, spike length, extrusion length, fertile spikelets spike⁻¹, 1000-grain weight, straw yield, harvest index and grain yield and negatively associated with infertile spikelets spike⁻¹. Effective tiller plant⁻¹ was positively related with spike length, extrusion length, fertile spikelets spike⁻¹, 1000-grain weight, straw yield, harvest index and grain yield and negatively associated with infertile spikelets spike⁻¹. Spike length was positively correlated with extrusion length, fertile spikelets spike⁻¹, 1000-grain weight, straw yield, harvest index and grain yield and negatively associated with infertile spikelets spike⁻¹ in both the years. Extrusion length had positive association with fertile spikelets spike⁻¹, 1000-grain weight, straw yield, harvest index and grain yield and negatively associated with infertile spikelets spike⁻¹. Fertile spikelets spike⁻¹ was positively correlated with 1000-grain weight, straw yield, harvest index and grain yield and negatively associated with infertile spikelets spike⁻¹. Infertile spikelets spike⁻¹ was negatively associated with 1000-grain weight, straw yield, harvest index and grain yield. 1000-grain weight had positive association with straw yield, harvest index and grain yield in both the years. Straw yield was positively correlated with harvest index and grain yield. Harvest index was positively associated with grain yield in both the years in rain-fed condition (Table 81).

4.8.1.2. One irrigation

In one irrigated wheat crops (I_1), plant height was positively correlated with effective tillers plant⁻¹, spike length, extrusion length, fertile spikelets spike⁻¹, 1000-grain weight, straw yield, harvest index and grain yield and negatively associated with infertile spikelets spike⁻¹. Effective tillers plant⁻¹ was positively related with spike length, extrusion length, fertile spikelets spike⁻¹, 1000-grain weight, straw yield, harvest index and grain yield and negatively associated with infertile spikelets spike⁻¹. Spike length had positive association with extrusion length, fertile spikelets spike⁻¹, 1000-grain weight, straw yield, harvest index and grain yield and negatively associated with infertile spikelets spike⁻¹. Extrusion length was positively associated with fertile spikelets spike⁻¹, 1000-grain weight, straw yield, harvest index and

grain yield and negatively associated with infertile spikelets spike⁻¹. Fertile spikelets spike⁻¹ was positively associated with 1000-grain weight, straw yield, harvest index and grain yield and negatively associated with infertile spikelets spike⁻¹. Infertile spikelets spike⁻¹ was negatively associated with 1000-grain weight, straw yield, harvest index and grain yield. 1000-grain weight was positively correlated with straw yield, harvest index and grain yield. Straw yield was positively related with harvest index and grain yield in both the years. Harvest index was positively associated with grain yield in both the years in one irrigated wheat crops (Table 82).

4.8.1.3. Two irrigations

In two irrigated wheat crops (I₂), plant height was positively correlated with effective tillers plant⁻¹, spike length, extrusion length, fertile spikelets spike⁻¹, 1000-grain weight, straw yield, harvest index and grain yield and negatively associated with infertile spikelets spike⁻¹. Effective tillers plant⁻¹ was positively related with spike length, extrusion length, fertile spikelets spike⁻¹, 1000-grain weight, straw yield, harvest index and grain yield and negatively associated with infertile spikelets spike⁻¹. Spike length had positive association with extrusion length, fertile spikelets spike⁻¹, 1000-grain weight, straw yield, harvest index and grain yield and negatively associated with infertile spikelets spike⁻¹. Extrusion length was positively associated with fertile spikelets spike⁻¹, 1000-grain weight, straw yield, harvest index and grain yield and negatively associated with infertile spikelets spike⁻¹. Fertile spikelets spike⁻¹ was positively associated with 1000-grain weight, straw yield, harvest index and grain yield and negatively associated with infertile spikelets spike⁻¹. Infertile spikelets spike⁻¹ was negatively associated with 1000-grain weight, straw yield, harvest index and grain yield. 1000-grain weight was positively correlated with straw yield, harvest index and grain yield. Straw yield was positively related with harvest index and grain yield in both the years. Harvest index was positively associated with grain yield in both the years in two irrigated wheat crops (Table 83).

4.8.1.4. Three irrigations

In three irrigated wheat crops (I₃), plant height was positively correlated with effective tillers plant⁻¹, spike length, extrusion length, fertile spikelets spike⁻¹, 1000-grain weight, straw yield, harvest index and grain yield and negatively associated with infertile spikelets spike⁻¹. Effective tillers plant⁻¹ was positively related with spike length, extrusion length, fertile spikelets spike⁻¹, 1000-grain weight, straw yield, harvest index and grain yield and negatively associated with

infertile spikelets spike⁻¹. Spike length had positive association with extrusion length, fertile spikelets spike⁻¹, 1000-grain weight, straw yield, harvest index and grain yield and negatively associated with infertile spikelets spike⁻¹. Extrusion length was positively associated with fertile spikelets spike⁻¹, 1000-grain weight, straw yield, harvest index and grain yield and negatively associated with infertile spikelets spike⁻¹. Fertile spikelets spike⁻¹ was positively associated with 1000-grain weight, straw yield, harvest index and grain yield and negatively associated with infertile spikelets spike⁻¹. Infertile spikelets spike⁻¹ was negatively associated with 1000-grain weight, straw yield, harvest index and grain yield. 1000-grain weight was positively correlated with straw yield, harvest index and grain yield. Straw yield was positively related with harvest index and grain yield in both the years. Harvest index was positively associated with grain yield in both the years in three irrigated wheat crops (Table 84).

In the present investigation, simple correlation coefficients between grain yield and its components were calculated for three irrigation regimes (Tables 81, 82, 83 and 84). In different irrigation treatment (I₀, I₁, I₂ and I₃), plant height was positively correlated with number of effective tillers plant⁻¹, spike length, extrusion length, fertile spikelets spike⁻¹, 1000-grain weight, straw yield and harvest index. Number of effective tillers plant⁻¹ had positive relation with spike length, extrusion length, fertile spikelets spike⁻¹, 1000-grain weight, straw yield and harvest index. Spike length was positively correlated with extrusion length, fertile spikelets spike⁻¹, 1000-grain weight, straw yield and harvest index. Extrusion length had positive association with fertile spikelets spike⁻¹, 1000-grain weight, straw yield and harvest index. Fertile spikelets spike⁻¹ was positively associated with 1000-grain weight, straw yield and harvest index. 1000-grain weight showed positive significant positive association with straw yield and harvest index. Straw yield was positively related with harvest index in both the years. The correlation coefficients for a particular pair of yield components varied greatly in different irrigation regimes and it was due to various factors affecting the different yield components at maturity. Grain yield was positively correlated with plant height, number of effective tillers plant⁻¹, spike length, extrusion length, fertile spikelets spike⁻¹, 1000-grain weight, straw yield and harvest index in both the year and grain yield was negatively associated with infertile spikelets spike⁻¹. This result is in agreement with Mandic *et al.* (2014) who found that grain yield had very strong positive correlation with 1000-grain weight. They also noticed that plant height was positively correlated with number of spikelets spike⁻¹, 1000-grain weight, number of spike m⁻² and grain yield. Rawson and

Ruwali (1972) suggested that high yields with uniform grain can be best obtained by increasing spikelet number, using branched ears, rather than by increasing seed set spikelet⁻¹. Islam (1977) found a significant positive correlation between grain yield plant⁻¹ and 100-seed weight. Similar result was reported by Bingham (1966) in wheat. Labuschagne and Van-Deventer (1992) reported that grain number and grain weight on both primary and secondary tillers were significantly correlated with yield at different moisture levels. Kheiralla *et al.* (1993) noticed the association between grain yield and harvest index only under non-stress condition. In the present study, straw weight was positively correlated with grain yield in all irrigation regimes. This result is in agreement with Chai *et al.* (1993). They noticed that grain weight/plant was correlated highly and significantly with dry weight plant⁻¹ in wheat. Rahman (1997) reported that grain yield was positively associated with biomass, harvest index, grain production rate and 1000-grain weight of wheat plant. Destro *et al.* (2001) reported that main stem grain yield responded positively and significantly to irrigation which was the main cause of increased yield in wheat. Bakhshandeh *et al.* (2004) observed a positive correlation between grain and biological yield in wheat, while the correlation between grain yield, 1000-grain weight and harvest index was not significant.

Table 81: Simple correlation coefficients between yield and yield components of wheat cultivars as influenced by rain-fed condition (I₀). Upper diagonal shows values in 2014-15 and lower diagonal shows values in 2015-16

	Plant height (cm)	Effective tillers plant ⁻¹	Spike length (cm)	Extrusion length(cm)	Fertile spikelets spike ⁻¹	Infertile spikelets spike ⁻¹	1000-grain weight (g)	Straw yield (kg ha ⁻¹)	Harvest index	Grain yield (kg ha ⁻¹)
	1	2	3	4	5	6	7	8	9	10
1	-	.946**	.990**	.946**	.970**	-.983**	.925**	.970**	.996**	.995**
2	.948**	-	.940**	.941**	.921**	-.884**	.846**	.950**	.950**	.956**
3	.994**	.944**	-	.914**	.993**	-.984**	.957**	.953**	.992**	.983**
4	.949**	.943**	.918**	-	.885**	-.898**	.796*	.981**	.940**	.963**
5	.974**	.922**	.992**	.888**	-	-.968**	.970**	.936**	.975**	.964**
6	-.987**	-.904**	-.987**	-.904**	-.967**	-	-.953**	-.928**	-.980**	-.969**
7	.927**	.848**	.955**	.799*	.974**	-.950**	-	.848**	.939**	.909**
8	.972**	.956**	.956**	.987**	.933**	-.929**	.846**	-	.968**	.987**
9	.998**	.954**	.992**	.944**	.977**	-.984**	.942**	.972**	-	.996**
10	.997**	.958**	.983**	.967**	.968**	-.972**	.910**	.989**	.998**	-

** . Correlation is significant at the 0.01 level (2-tailed).

* . Correlation is significant at the 0.05 level (2-tailed).

Table 82: Simple correlation coefficients between yield and yield components of wheat cultivars as influenced by one irrigation (I₁). Upper diagonal shows values in 2014-15 and lower diagonal shows values in 2015-16

	Plant height (cm)	Effective tillers plant ⁻¹	Spike length (cm)	Extrusion length(cm)	Fertile spikelets spike ⁻¹	Infertile spikelets spike ⁻¹	1000-grain weight (g)	Straw yield (kg ha ⁻¹)	Harvest index	Grain yield (kg ha ⁻¹)
	1	2	3	4	5	6	7	8	9	10
1	-	.894**	.992**	.942**	.979**	-.794*	.802*	.991**	.988**	.994**
2	.898**	-	.905**	.966**	.863**	-.875**	.510	.928**	.911**	.922**
3	.996**	.907**	-	.949**	.993**	-.843**	.813*	.979**	.991**	.988**
4	.944**	.968**	.951**	-	.927**	-.907**	.600	.963**	.973**	.970**
5	.980**	.862**	.996**	.926**	-	-.830*	.854**	.959**	.982**	.971**
6	-.795*	-.874**	-.844**	-.908**	-.825*	-	-.513	-.797*	-.861**	-.828*
7	.801*	.513	.814*	.602	.855**	-.509	-	.730*	.757*	.743*
8	.992**	.929**	.981**	.961**	.958**	-.799*	.732*	-	.984**	.996**
9	.989**	.912**	.994**	.975**	.981**	-.863**	.758*	.986**	-	.995**
10	.996**	.924**	.990**	.971**	.973**	-.830*	.746*	.998**	.997**	-

** . Correlation is significant at the 0.01 level (2-tailed).

* . Correlation is significant at the 0.05 level (2-tailed).

Table 83: Simple correlation coefficients between yield and yield components of wheat cultivars as influenced by two irrigations (I₂). Upper diagonal shows values in 2014-15 and lower diagonal shows values in 2015-16

	Plant height (cm)	Effective tillers plant ⁻¹	Spike length (cm)	Extrusion length(cm)	Fertile spikelets spike ⁻¹	Infertile spikelets spike ⁻¹	1000-grain weight (g)	Straw yield (kg ha ⁻¹)	Harvest index	Grain yield (kg ha ⁻¹)
	1	2	3	4	5	6	7	8	9	10
1	-	.811*	.991**	.960**	.986**	-.822*	.727*	.986**	.980**	.989**
2	.813*	-	.798*	.914**	.837**	-.967**	.212	.815*	.884**	.846**
3	.992**	.797*	-	.966**	.994**	-.820*	.735*	.997**	.985**	.996**
4	.962**	.915**	.965**	-	.985**	-.902**	.550	.975**	.993**	.985**
5	.987**	.836**	.995**	.984**	-	-.845**	.676	.996**	.992**	.997**
6	-.816*	-.968**	-.811*	-.895**	-.836**	-	-.255	-.824*	-.890**	-.853**
7	.726*	.214	.737*	.552	.679	-.241	-	.718*	.616	.681
8	.987**	.818*	.999**	.977**	.998**	-.813*	.720*	-	.987**	.997**
9	.982**	.885**	.986**	.994**	.993**	-.882**	.618	.989**	-	.996**
10	.988**	.847**	.997**	.986**	.998**	-.845**	.685	.998**	.999**	-

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

Table 84: Simple correlation coefficients between yield and yield components of wheat cultivars as influenced by three irrigations (I₃). Upper diagonal shows values in 2014-15 and lower diagonal shows values in 2015-16

	Plant height (cm)	Effective tillers plant ⁻¹	Spike length (cm)	Extrusion length(cm)	Fertile spikelets spike ⁻¹	Infertile spikelets spike ⁻¹	1000-grain weight (g)	Straw yield (kg ha ⁻¹)	Harvest index	Grain yield (kg ha ⁻¹)
	1	2	3	4	5	6	7	8	9	10
1	-	.757*	.988**	.987**	.991**	-.960**	.773*	.988**	.986**	.991**
2	.758*	-	.746*	.819*	.701	-.593	.197	.735*	.795*	.758*
3	.989**	.749*	-	.990**	.993**	-.948**	.776*	.999**	.997**	.999**
4	.989**	.821*	.994**	-	.982**	-.914**	.696	.988**	.997**	.993**
5	.994**	.699	.995**	.981**	-	-.957**	.815*	.993**	.986**	.993**
6	-.837**	-.661	-.839**	-.833*	-.830*	-	-.890**	-.951**	-.929**	-.946**
7	.776*	.198	.775*	.697	.816*	-.573	-	.782*	.727*	.764*
8	.986**	.737*	.997**	.987**	.995**	-.830*	.783*	-	.995**	.999**
9	.989**	.797*	.998**	.998**	.985**	-.844**	.729*	.998**	-	.998**
10	.994**	.759*	.998**	.995**	.994**	-.840**	.765*	.998**	.999**	-

*, Correlation is significant at the 0.05 level (2-tailed).

**, Correlation is significant at the 0.01 level (2-tailed).

4.8.2. Effect of nitrogen

Simple correlation co-efficient between yield and yield components of wheat as influenced by irrigation are shown in Tables 85, 86, 87 and 88.

4.8.2.1. Control

In control wheat crops (N_0) plant height was positively correlated with effective tillers plant⁻¹, spike length, extrusion length, fertile spikelets spike⁻¹, 1000-grain weight, straw yield, harvest index and grain yield and negatively associated with infertile spikelets spike⁻¹. Effective tiller plant⁻¹ was positively related with spike length, extrusion length, fertile spikelets spike⁻¹, 1000-grain weight, straw yield, harvest index and grain yield and negatively associated with infertile spikelets spike⁻¹. Spike length was positively correlated with extrusion length, fertile spikelets spike⁻¹, 1000-grain weight, straw yield, harvest index and grain yield and negatively associated with infertile spikelets spike⁻¹ in both the years. Extrusion length had positive association with fertile spikelets spike⁻¹, 1000-grain weight, straw yield, harvest index and grain yield and negatively associated with infertile spikelets spike⁻¹. Fertile spikelets spike⁻¹ was positively correlated with 1000-grain weight, straw yield, harvest index and grain yield and negatively associated with infertile spikelets spike⁻¹. Infertile spikelets spike⁻¹ was negatively associated with 1000-grain weight, straw yield, harvest index and grain yield. 1000-grain weight had positive association with straw yield, harvest index and grain yield in both the years. Straw yield was positively correlated with harvest index and grain yield. Harvest index was positively associated with grain yield in both the years in rain-fed condition (Table 85).

4.8.2.2. Basal application of nitrogen

In wheat crops with basal application of nitrogen (N_1), plant height was positively correlated with effective tillers plant⁻¹, spike length, extrusion length, fertile spikelets spike⁻¹, 1000-grain weight, straw yield, harvest index and grain yield and negatively associated with infertile spikelets spike⁻¹. Effective tillers plant⁻¹ was positively related with spike length, extrusion length, fertile spikelets spike⁻¹, 1000-grain weight, straw yield, harvest index and grain yield and negatively associated with infertile spikelets spike⁻¹. Spike length had positive association with extrusion length, fertile spikelets spike⁻¹, 1000-grain weight, straw yield, harvest index and grain yield and negatively associated with infertile spikelets spike⁻¹. Extrusion length was positively associated with fertile spikelets spike⁻¹, 1000-grain weight, straw yield, harvest index and grain yield and negatively associated with infertile spikelets

spike⁻¹. Fertile spikelets spike⁻¹ was positively associated with 1000-grain weight, straw yield, harvest index and grain yield and negatively associated with infertile spikelets spike⁻¹. Infertile spikelets spike⁻¹ was negatively associated with 1000-grain weight, straw yield, harvest index and grain yield. 1000-grain weight was positively correlated with straw yield, harvest index and grain yield. Straw yield was positively related with harvest index and grain yield in both the years. Harvest index was positively associated with grain yield in both the years in one irrigated wheat crops (Table 86).

4.8.2.3. Three split applications of nitrogen

In wheat crops with three split applications of nitrogen (N₂), plant height was positively correlated with effective tillers plant⁻¹, spike length, extrusion length, fertile spikelets spike⁻¹, 1000-grain weight, straw yield, harvest index and grain yield and negatively associated with infertile spikelets spike⁻¹. Effective tillers plant⁻¹ was positively related with spike length, extrusion length, fertile spikelets spike⁻¹, 1000-grain weight, straw yield, harvest index and grain yield and negatively associated with infertile spikelets spike⁻¹. Spike length had positive association with extrusion length, fertile spikelets spike⁻¹, 1000-grain weight, straw yield, harvest index and grain yield and negatively associated with infertile spikelets spike⁻¹. Extrusion length was positively associated with fertile spikelets spike⁻¹, 1000-grain weight, straw yield, harvest index and grain yield and negatively associated with infertile spikelets spike⁻¹. Fertile spikelets spike⁻¹ was positively associated with 1000-grain weight, straw yield, harvest index and grain yield and negatively associated with infertile spikelets spike⁻¹. Infertile spikelets spike⁻¹ was negatively associated with 1000-grain weight, straw yield, harvest index and grain yield. 1000-grain weight was positively correlated with straw yield, harvest index and grain yield. Straw yield was positively related with harvest index and grain yield in both the years. Harvest index was positively associated with grain yield in both the years in two irrigated wheat crops (Table 87).

4.8.1.4. Four split applications of nitrogen

In wheat crops with four split applications of nitrogen (N₃), plant height was positively correlated with effective tillers plant⁻¹, spike length, extrusion length, fertile spikelets spike⁻¹, 1000-grain weight, straw yield, harvest index and grain yield and negatively associated with infertile spikelets spike⁻¹. Effective tillers plant⁻¹ was positively related with spike length, extrusion length, fertile spikelets spike⁻¹, 1000-grain weight, straw yield, harvest index and grain yield and negatively associated with infertile spikelets spike⁻¹. Spike length had positive

association with extrusion length, fertile spikelets spike⁻¹, 1000-grain weight, straw yield, harvest index and grain yield and negatively associated with infertile spikelets spike⁻¹. Extrusion length was positively associated with fertile spikelets spike⁻¹, 1000-grain weight, straw yield, harvest index and grain yield and negatively associated with infertile spikelets spike⁻¹. Fertile spikelets spike⁻¹ was positively associated with 1000-grain weight, straw yield, harvest index and grain yield and negatively associated with infertile spikelets spike⁻¹. Infertile spikelets spike⁻¹ was negatively associated with 1000-grain weight, straw yield, harvest index and grain yield. 1000-grain weight was positively correlated with straw yield, harvest index and grain yield. Straw yield was positively related with harvest index and grain yield in both the years in three irrigated wheat crops (Table 88).

In the present investigation, simple correlation coefficients between grain yield and its components were calculated for three nitrogen treatments (Tables 85, 86, 87 and 88). In different nitrogen treatment (N₀, N₁, N₂ and N₃) plant height was positively correlated with number of effective tillers plant⁻¹, spike length, extrusion length, fertile spikelets spike⁻¹, 1000-grain weight, straw yield and harvest index. Number of effective tillers plant⁻¹ had positive relation with spike length, extrusion length, fertile spikelets spike⁻¹, 1000-grain weight, straw yield and harvest index. Fertile spikelets spike⁻¹ was positively associated with 1000-grain weight, straw yield and harvest index. 1000-grain weight showed positive significant positive association with straw yield and harvest index. The correlation coefficients for a particular pair of yield components varied greatly in different nitrogen treatments and it was due to various factors affecting the different yield components at maturity. Grain yield was positively correlated with plant height, number of effective tillers plant⁻¹, spike length, extrusion length, fertile spikelets spike⁻¹, 1000-grain weight, straw yield and harvest index in both the year and grain yield was negatively associated with infertile spikelets spike⁻¹. This result is in agreement with Mandic *et al.* (2014) who found that grain yield had very strong positive correlation with 1000-grain weight. They also noticed that plant height was positively correlated with number of spikelets spike⁻¹, 1000-grain weight, number of spike m⁻² and grain yield. Kumar *et al.* (2003) reported that Plant heights were found positively correlated with nitrogen levels. Alves *et al.* (2015) reported there were positive correlations between the doses of N with the number of spike and grain yield and between numbers of spike with the grain yield.

Table 85: Simple correlation coefficients between yield and yield components of wheat cultivars as influenced by control (N₀). Upper diagonal shows values in 2014-15 and lower diagonal shows values in 2015-16

	Plant height (cm)	Effective tillers plant ⁻¹	Spike length (cm)	Extrusion length(cm)	Fertile spikelets spike ⁻¹	Infertile spikelets spike ⁻¹	1000-grain weight (g)	Straw yield (kg ha ⁻¹)	Harvest index	Grain yield (kg ha ⁻¹)
	1	2	3	4	5	6	7	8	9	10
1	-	.748*	.991**	.753*	.982**	-.923**	.894**	.968**	.990**	.983**
2	.749*	-	.719*	.898**	.753*	-.654	.432	.825*	.785*	.812*
3	.993**	.721*	-	.711*	.977**	-.951**	.926**	.972**	.990**	.984**
4	.750*	.896**	.708*	-	.767*	-.655	.421	.804*	.799*	.810*
5	.984**	.749*	.979**	.761*	-	-.909**	.889**	.952**	.978**	.969**
6	-.921**	-.652	-.949**	-.650	-.910**	-	-.878**	-.895**	-.936**	-.923**
7	.895**	.431	.927**	.417	.894**	-.877**	-	.838**	.872**	.853**
8	.967**	.826*	.973**	.801*	.953**	-.889**	.836**	-	.987**	.996**
9	.988**	.788*	.995**	.796*	.979**	-.934**	.871**	.988**	-	.998**
10	.981**	.813*	.983**	.808*	.971**	-.919**	.852**	.998**	.999**	-

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

Table 86: Simple correlation coefficients between yield and yield components of wheat cultivars as influenced by basal (N₁) application of nitrogen. Upper diagonal shows values in 2014-15 and lower diagonal shows values in 2015-16

	Plant height (cm)	Effective tillers plant ⁻¹	Spike length (cm)	Extrusion length(cm)	Fertile spikelets spike ⁻¹	Infertile spikelets spike ⁻¹	1000-grain weight (g)	Straw yield (kg ha ⁻¹)	Harvest index	Grain yield (kg ha ⁻¹)
	1	2	3	4	5	6	7	8	9	10
1	-	.695	.982**	.848**	.940**	-.466	.642	.972**	.986**	.986**
2	.697	-	.664	.850**	.594	-.452	-.036	.671	.771*	.706
3	.983**	.665	-	.802*	.971**	-.562	.691	.952**	.974**	.963**
4	.847**	.853**	.800*	-	.657	-.582	.235	.819*	.905**	.851**
5	.942**	.597	.975**	.658	-	-.459	.739*	.911**	.912**	.918**
6	-.487	-.480	-.580	-.601	-.468	-	-.194	-.490	-.568	-.495
7	.643	-.034	.695	.233	.742*	-.193	-	.593	.556	.584
8	.971**	.670	.951**	.817*	.910**	-.510	.595	-	.958**	.996**
9	.984**	.773*	.975**	.904**	.914**	-.596	.557	.955**	-	.978**
10	.988**	.708	.964**	.850**	.919**	-.518	.585	.998**	.976**	-

** . Correlation is significant at the 0.01 level (2-tailed).

* . Correlation is significant at the 0.05 level (2-tailed).

Table 87: Simple correlation coefficients between yield and yield components of wheat cultivars as influenced by three split (N₂) applications of nitrogen. Upper diagonal shows values in 2014-15 and lower diagonal shows values in 2015-16

	Plant height (cm)	Effective tillers plant ⁻¹	Spike length (cm)	Extrusion length(cm)	Fertile spikelets spike ⁻¹	Infertile spikelets spike ⁻¹	1000-grain weight (g)	Straw yield (kg ha ⁻¹)	Harvest index	Grain yield (kg ha ⁻¹)
	1	2	3	4	5	6	7	8	9	10
1	-	.742*	.979**	.923**	.967**	-.661	.669	.972**	.992**	.984**
2	.744*	-	.722*	.834*	.663	-.730*	.099	.711*	.804*	.740*
3	.980**	.725*	-	.870**	.970**	-.687	.708*	.970**	.983**	.977**
4	.925**	.837*	.869**	-	.827*	-.679	.375	.872**	.931**	.893**
5	.966**	.658	.971**	.826*	-	-.683	.749*	.934**	.960**	.949**
6	-.660	-.725*	-.684	-.672	-.682	-	-.141	-.707*	-.728*	-.711*
7	.671	.102	.709*	.374	.751*	-.140	-	.640	.606	.635
8	.973**	.713*	.973**	.871**	.936**	-.710*	.639	-	.972**	.997**
9	.991**	.805*	.984**	.932**	.959**	-.726*	.605	.970**	-	.985**
10	.985**	.742*	.978**	.895**	.950**	-.714*	.637	.998**	.984**	-

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

Table 88: Simple correlation coefficients between yield and yield components of wheat cultivars as influenced by four split (N₃) applications of nitrogen. Upper diagonal shows values in 2014-15 and lower diagonal shows values in 2015-16

	Plant height (cm)	Effective tillers plant ⁻¹	Spike length (cm)	Extrusion length(cm)	Fertile spikelets spike ⁻¹	Infertile spikelets spike ⁻¹	1000-grain weight (g)	Straw yield (kg ha ⁻¹)	Harvest index	Grain yield (kg ha ⁻¹)
	1	2	3	4	5	6	7	8	9	10
1	-	.720*	.989**	.872**	.960**	-.430	.616	.972**	.977**	.984**
2	.722*	-	.714*	.822*	.611	-.580	-.037	.700	.791*	.732*
3	.990**	.715*	-	.857**	.958**	-.522	.617	.982**	.988**	.990**
4	.871**	.821*	.856**	-	.769*	-.626	.237	.835**	.895**	.861**
5	.959**	.604	.959**	.763*	-	-.421	.721*	.932**	.948**	.947**
6	-.650	-.895**	-.692	-.821*	-.573	-	.068	-.507	-.593	-.517
7	.617	-.036	.619	.236	.729*	.027	-	.564	.531	.559
8	.971**	.699	.985**	.833*	.930**	-.644	.567	-	.961**	.997**
9	.975**	.792*	.987**	.893**	.944**	-.785*	.533	.957**	-	.978**
10	.985**	.733*	.993**	.860**	.945**	-.679	.561	.999**	.975**	-

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

4.9. Water use

4.9.1. Consumptive use of water

The irrigation levels exhibited significant influence on consumptive use of water (CUW) in both the growing seasons which are presented in Table 89a for first year (2014-15) and in Table 89b for second year (2015-16). The total amount of water consumption increased with increasing irrigation levels in both the years. The highest consumptive use of water (CUW) was recorded in three irrigations (I_3) followed by two irrigations (I_2) and one irrigation (I_1) and the lowest consumptive use of water (CUW) was observed in rain-fed (I_0) wheat crops in both the years. Similar results were reported by Pal *et al.*, 1996, Ju-Hui *et al.*, 2000 and Mollah 2007. Jana and Mitra (2004) noticed that water use increased and water use efficiency decreased with increasing number of irrigations. Soni and Lehria (1999) also observed that total water use was highest with two irrigations, whereas water use efficiency was highest in the crops growing without irrigation. Ju-Hui *et al.* (2000) noticed that the total water consumption was decreased with decreasing amount of water, but the use of water stored in the soil was increased, particularly from deeper soil layers. Mollah and Paul (2011) stated that irrigated plants had higher CUW than the rain-fed plants in barley.

There was no significant effect on consumptive use of water (CUW) in different wheat variety in both the years are given in Table 90a for first year (2014-15) and in Table 90b for second year (2015-16). Between the two varieties, BARI Gom 24 had higher CUW than BARI Gom 26.

The effects of nitrogen on consumptive use of water in both the years are presented in Table 91a for first year (2014-15) and in Table 91b for second year (2015-16). The difference in consumptive use of water (CUW) due to split applications of nitrogen was not statistically significant in both the years. Among the treatment, the highest CUW was found in four split (N_3) followed by three split (N_2) and basal (N_1) applications of nitrogen and the lowest CUW was in control (N_0). Mollah and Paul (2011) stated that CUW was to increase with the increase of fertilizer level.

Different treatment combinations of irrigation and nitrogen had significant influence on consumptive use of water (CUW) in both the growing seasons and are shown in Table 92a for first year (2014-15) and in Table 92b for second year (2015-16). The highest consumptive use of water (CUW) was recorded in the treatment combination of three irrigations (I_3) $\times$ four splits (N_3) application which was statistically identical with $I_3 \times N_2$, $I_3 \times N_1$ and $I_3 \times N_0$ in

both the years. The lowest value was found in rain-fed (I_0) $\times$ control (N_0) which was statistically similar with $I_0 \times N_1$, $I_0 \times N_2$ and $I_0 \times N_3$ in both the growing seasons.

4.9.2. Water use efficiency

Water use efficiency for wheat at different irrigation schedule are given in Table 89a for first year (2014-15) and in Table 89b for second year (2015-16). There was significant effect of irrigation levels on water use efficiency (WUE) in both the years. The WUE decreased with increasing irrigation application rates. The low irrigation treatment had higher WUE than that of high irrigation treatment. The highest WUE was observed in rain-fed (I_0) condition followed by one (I_1) and two (I_2) irrigations and the lowest WUE was found in three irrigations (I_3) in both the growing seasons. The rain-fed or minimum irrigated plants exhibited higher water use efficiency in the present study. Similar results were reported by Soni and Lehria 1999, Ju-Hui *et al.*, 2000, Kang *et al.*, 2002, Mahmood and Ahmad, 2005, Ram *et al.*, 2013, Abdelraouf *et al.*, 2013 and M'hamed *et al.*, 2015 in wheat, Begum and Paul 1993 in mustard. Mollah (2007) and Bahadur (2008) also found similar result with barley. Maurya and Singh (2008) also reported a decrease in WUE with an increase in irrigation levels due to proportionately less increase in biomass with increase in water consumption. Similarly, Li *et al.* (2005) reported that WUE decreased with increasing in irrigation and because grain yield did not increase linearly with irrigation, excessive irrigation even decreased grain production. Wang *et al.* (2012) stated that the low crop water-use, related to high irrigation treatments, was most likely due to high permeation over the root layer and high evapo-transpiration. Khan *et al.* (2007) stated that WUE was increased when the irrigation intervals increased. Mandal *et al.* (2003) reported that WUE of wheat decreased with increase in irrigation levels. Mollah and Paul (2011) stated that the highest WUE was in no irrigation treatment followed by irrigation treatment in barley. Similar findings were also reported in wheat by Rahman and Islam (1991).

Variety had no significant effect on water use efficiency (WUE) in both the years and is given in Table 90a for first year (2014-15) and in Table 90b for second year (2015-16). Between the two varieties, BARI Gom 26 had higher water use efficiency than BARI Gom 24.

Split applications of nitrogen had significant effect on water use efficiency (WUE) in both the years and are presented in Table 91a for first year (2014-15) and in Table 91b for second year (2015-16). The highest water use efficiency was recorded in three split (N_2) applications of

nitrogen which was statistically identical with four split (N_3) and basal (N_1) applications of nitrogen and the lowest value was found in control (N_0) in both the growing seasons. Similar result was recorded in wheat (Howell 2001, Wang *et al.*, 2012, Abdelraouf *et al.*, 2013 and Abderrazzak *et al.*, 2013). Mandal *et al.* (2003) reported that in contrast to irrigation levels, nitrogen management treatments registered higher WUE of wheat compared to control. Mollah and Paul (2011) stated that WUE was to increase with the increase of fertilizer level. Bushong *et al.* (2014) stated that with adequate moisture, the addition of nitrogen fertilizer stimulates root growth, which can easily promote the acquisition of more soil water and/or soil nutrients.

Water use efficiency (WUE) was significantly influenced by the interaction of irrigation and nitrogen in both the years and is shown in Table 92a for first year (2014-15) and in Table 92b for second year (2015-16). The highest water use efficiency (WUE) was obtained in treatment combination of rain-fed condition (I_0) $\times$ three split (N_2) application of nitrogen followed by $I_0 \times N_3$, $I_0 \times N_1$ and the lowest value was found in three irrigations (I_3) $\times$ control (N_0) in both the growing seasons.

Table 89a: Effect of irrigation on Consumptive use of water and water use efficie of wheat (2014-2015)

Irrigation	Consumptive use of water (mm)	Water use Efficiency (kg ha ⁻¹ mm ⁻¹)
I ₀	206.696 d	11.074 a
I ₁	341.619 c	8.176 b
I ₂	468.892 b	8.086 b
I ₃	603.451 a	6.754 c
CV (%)	1.218	4.180

In a column, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

Table 89b: Effect of irrigation on Consumptive use of water and water use efficiency of wheat (2015-2016)

Irrigation	Consumptive use of water(mm)	Water use Efficiency (kg ha ⁻¹ mm ⁻¹)
I ₀	220.253 d	10.629 a
I ₁	356.172 c	8.203 b
I ₂	484.385 b	8.081 b
I ₃	619.938 a	6.808 c
CV (%)	1.183	4.156

In a column, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

Table 90a: Effect of variety on Consumptive use of water and water use efficiency of wheat (2014-2015)

Variety	Consumptive use of water(mm)	Water use Efficiency (kg ha ⁻¹ mm ⁻¹)
V ₁	405.372 a	8.459 a
V ₂	404.958 a	8.586 a
CV (%)	1.218	4.180

In a column, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

Table 90b: Effect of variety on Consumptive use of water and water use efficiency of wheat (2015-2016)

Variety	Consumptive use of water(mm)	Water use Efficiency (kg ha ⁻¹ mm ⁻¹)
V ₁	420.396 a	8.418 a
V ₂	419.978 a	8.542 a
CV (%)	1.183	4.156

In a column, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

Table 91a: Effect of nitrogen on Consumptive use of water and water use efficiency of wheat (2014-2015)

Nitrogen	Consumptive use of water(mm)	Water use Efficiency (kg ha ⁻¹ mm ⁻¹)
N ₀	404.074 a	6.253 b
N ₁	404.732 a	8.937 a
N ₂	405.332 a	9.622 a
N ₃	406.521 a	9.278 a
CV (%)	1.218	4.180

In a column, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

Table 91b: Effect of nitrogen on Consumptive use of water and water use efficiency of wheat (2015-2016)

Nitrogen	Consumptive use of water(mm)	Water use Efficiency (kg ha ⁻¹ mm ⁻¹)
N ₀	419.088 a	6.214 b
N ₁	419.751 a	8.894 a
N ₂	420.356 a	9.577 a
N ₃	421.553 a	9.236 a
CV (%)	1.183	4.156

In a column, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

Table 92a: Interaction effect of irrigation and nitrogen management on Consumptive use of water and water use efficiency of wheat (2014-2015)

Interaction (Irrigation × Nitrogen)	Consumptive use of water (mm)	Water use Efficiency (kg ha ⁻¹ mm ⁻¹)
I ₀ N ₀	219.192 d	9.024 ef
I ₀ N ₁	219.858 d	11.408 c
I ₀ N ₂	220.65 d	12.136 a
I ₀ N ₃	221.313 d	11.726 b
I ₁ N ₀	355.357 c	6.319 k
I ₁ N ₁	356.004 c	8.306 h
I ₁ N ₂	356.444 c	9.053 ef
I ₁ N ₃	356.883 c	8.666 g
I ₂ N ₀	482.846 b	5.225 l
I ₂ N ₁	483.500 b	8.783 fg
I ₂ N ₂	484.088 b	9.548 d
I ₂ N ₃	487.108 b	9.146 e
I ₃ N ₀	618.968 a	4.443 m
I ₃ N ₁	619.642 a	7.250 j
I ₃ N ₂	620.242 a	7.751 i
I ₃ N ₃	620.908 a	7.574 i
CV (%)	1.218	4.180

In a column, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

Table 92b: Interaction effect of irrigation and nitrogen management on Consumptive use of water and water use efficiency of wheat (2015-2016)

Interaction Irrigation × Nitrogen)	Consumptive use of water (mm)	Water use Efficiency (kg ha ⁻¹ mm ⁻¹)
I ₀ N ₀	484.192 d	8.822 fg
I ₀ N ₁	484.858 d	11.155 c
I ₀ N ₂	485.650 d	11.869 a
I ₀ N ₃	486.313 d	11.471 b
I ₁ N ₀	620.357 c	6.315 k
I ₁ N ₁	621.004 c	8.301 h
I ₁ N ₂	621.444 c	9.048 ef
I ₁ N ₃	621.883 c	8.662 g
I ₂ N ₀	747.846 b	5.242 l
I ₂ N ₁	748.500 b	8.812 fg
I ₂ N ₂	749.088 b	9.579 d
I ₂ N ₃	752.108 b	9.178 e
I ₃ N ₀	883.958 a	4.478 m
I ₃ N ₁	884.642 a	7.307 j
I ₃ N ₂	885.242 a	7.812 i
I ₃ N ₃	885.908 a	7.634 i
CV (%)	1.183	4.156

In a column, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

4.10. Nitrogen content, Protein content, N-uptake and N use efficiency

4.10.1. Nitrogen content in grain

Irrigation treatments significantly influenced the nitrogen content (%) in grain in both the growing seasons and are presented in Table 93a for first year (2014-15) and in Table 93b for second year (2015-16). The total amount of nitrogen content (%) in grain increased with increasing irrigation levels in both the years. The highest nitrogen content (%) in grain was recorded in three irrigations (I_3) which was statistically similar with two (I_2) followed by one (I_1) irrigation treatments and the lowest value was found in rain-fed (I_0) condition in both the years. Similar result was observed in wheat (Ciobanu *et al.*, 1995 and Rahman 2004).

Nitrogen content (%) in grain was not significant due to variety in both the years are given in Table 94 for first year (2014-15) and in Table 94b for second year (2015-16). Between the two varieties, BARI Gom 24 had higher nitrogen content (%) than BARI Gom 26 in grain.

All the treatments receiving nitrogen fertilizer showed better performance on nitrogen content (%) in grain than control (N_0) in both the growing seasons and are presented in Table 95a for first year (2014-15) and in Table 95b for second year (2015-16). In the present study, the highest nitrogen content (%) was recorded in three split applications of nitrogen which was statistically at par with four split (N_3) and basal (N_1) application of nitrogen and the lowest nitrogen content (%) was found in control (N_0). Rahman *et al.* (2011) also reported that three equal split application of nitrogen was effective in increasing nitrogen content of wheat. Similar result was reported in wheat (Singh and Uttam 1995, Vukovic *et al.*, 2008, Shirazi *et al.*, 2014 and Inwati *et al.*, 2018). Kucharski and Chodan (1991) reported that increasing N rates increased total N content in wheat seed. Chandurkar *et al.* (2007) stated that the highest N content in grain was obtained with increasing rate of nitrogen. Khursheed and Mahammad (2015) reported that total N content was increased significantly by applying N as urea. These results agreed with those found by Lopez-Bellido *et al.* (2008) and Giambalvo *et al.* (2010), due to an increase in nitrogen uptake which consider as a building blocks in the synthesis of proteins.

The interaction effect of irrigation and nitrogen was significant for nitrogen content (%) in grain in both the years and are given in Table 96a for first year (2014-15) and in Table 96b for second year (2015-16). The highest nitrogen content (%) was recorded by the treatment combinations of three irrigations (I_3) $\times$ three splits (N_2) which was statistically identical with three irrigations (I_3) $\times$ four splits (N_3) application of nitrogen and the lowest value was given by the treatment combinations of rain-fed (I_0) $\times$ control (N_0) in both the growing seasons.

4.10.2. Nitrogen content in straw

The irrigation levels exhibited significant influence on nitrogen content (%) in straw in both the growing seasons and are presented in Table 93a for first year (2014-15) and Table 93b for second year (2015-16). The total amount of nitrogen content (%) in straw was increased with increasing irrigation levels in both the years. The highest amount of nitrogen content (%) in straw was recorded in three irrigations (I_3) which was statistically identical with two irrigations (I_2) and the lowest value was observed in rain-fed (I_0) wheat crops in both the years. Similar result was observed in wheat by Ciobanu *et al.*, 1995 and Rahman 2004.

There was no significant effect on nitrogen content (%) in straw in wheat varieties in both the years and are shown in Table 94a for first year (2014-15) and in Table 94b for second year (2015-16). Between the two varieties, BARI Gom 24 had higher nitrogen content (%) than BARI Gom 26 in straw.

Nitrogen content (%) in wheat straw was significantly influenced by split applications of nitrogen in both the years is presented in Table 95a for first year (2014-15) and Table 95b for second year (2015-16). The highest nitrogen percentage in straw was observed in three split application of nitrogen which was statistically similar with four split (N_3) and basal (N_1) application of nitrogen and the lowest value was found in control (N_0) in both the years. Kumar *et al.* (1995b) reported that increasing levels of nitrogen increased the N content (%) in straw. Similar result was recorded in wheat by Memon and Jamro (1988) and Inwati *et al.* (2018). Chandurkar *et al.* (2007) determined higher nitrogen content in grain and straw of wheat with increasing N fertilizer rates. Liu *et al.* (1997) observed that NPK fertilizer increased straw N and Cu concentration.

Different treatment combinations of irrigation and nitrogen had significant influence on nitrogen content (%) in straw in both the growing seasons and are given in Table 96a for first year (2014-15) and Table 96b for second year (2015-16). The highest nitrogen content (%) in straw was recorded in the treatment combination of three irrigations (I_3) $\times$ three splits (N_2) application of nitrogen which was statistically identical with $I_3 \times N_3$, $I_3 \times N_1$, $I_2 \times N_1$, $I_2 \times N_2$ and $I_2 \times N_3$ in both the years. The lowest value was found in rain-fed (I_0) $\times$ control (N_0) in both the growing seasons.

4.10.3. Grain protein content

Grain protein content (%) was significantly influenced by irrigation treatments in both the growing seasons and are presented in Table 93a for first year (2014-15) and in Table 93b for second year (2015-16). The highest grain protein content (%) was recorded from the crop receiving three irrigations (I_3) which was statistically at par with by two (I_2) followed one (I_1) irrigations and the lowest value was obtained from the non-irrigated crop in both the years. Similar results were recorded in wheat by many researchers (Sarker and Paul 1997, Rahman *et al.*, 2001 and Mohammadi *et al.*, 2015). Ngwako and Mashiqqa (2013) stated that the grain protein content was increased in irrigated crops over no irrigation treatment. Pandit *et al.* (2001) stated that grain protein content (%) and grain protein yield were increased by irrigation. They also observed the relationship of grain yield with grain protein content (%) and grain protein yield were significantly positive due to irrigation.

Grain protein content (%) was not significant due to variety in both the growing seasons and are given in Table 94a for first year (2014-15) and in Table 94b for second year (2015-16). Between the two varieties, BARI Gom 24 had higher grain protein content (%) than BARI Gom 26.

The effects of nitrogen on grain protein content in both the years and are presented in Table 95a for first year (2014-15) and in Table 95b for second year (2015-16). The highest grain protein content (%) was recorded in three split (N_2) applications of nitrogen which was statistically similar with four split (N_3) and basal (N_1) applications of nitrogen in both the years. Regarding protein content in the grains for split application of nitrogen fertilizer, applications of fertilizer in the late crop stages had the highest grain protein content. These results revealed that timing of fertilizer application is more vital to affect quality of seed. Sufficient N fertilizer application during early vegetative growth stages significantly increased tiller formation in wheat crop (Sohail *et al.*, 2013); however, it did not ensure to enhance protein contents and late-season N fertilizer application will be needed to improve grain protein content. According to Tonon (2010), protein in the grain is slowly accumulated in wheat endosperm tissues at 20 days after anthesis. During this period, 40% of proteins are reserved for higher classes and after 45 days, the grain protein stock is complete. In this stage, nitrogen availability is required for protein synthesis in wheat grains. Nutrient deficiency in the plant results in grain protein synthesis decrease and grain starch synthesis increase, generating grains with low protein concentration (Rosa Filho 2010). The treatments receiving nitrogen fertilizer showed better performance on grain protein content (%) than

control in both the growing seasons. Similar results were observed in wheat (Singh and Uttam 1995, Vukovic *et al.*, 2008, Rahimizadeh *et al.*, 2010, Szmigiel *et al.*, 2014 and Mohammadi *et al.*, 2015). Pandit *et al.* (2002) reported that the highest grain protein content (%) was obtained from three split application of nitrogen in wheat. Application of nitrogen in four splits, last splits applied after anthesis, did not show any improvement of grain protein content (%). Garmashov *et al.* (1985) stated that grain protein content could be increased by split application of nitrogen at flowering stage. Sadat *et al.* (2008) stated that the splits application of nitrogen significantly affect on protein content of wheat grain. The highest grain protein content (12.63%) was obtained through the treatment with 18% N at land preparation+ 36% N at CRI+ 46% N at PI. The treatment produced highest grain protein content in wheat might be due to fact of applying nitrogen at all growth and productive stages that enhanced the increase seed protein accumulation. El-Far and El- Negar (1995) reported that increased protein was obtained with split application of nitrogen. Memon and Jamro (1988) observed that wheat seed protein content increased from 8.7% without N to 14.5% with 240 kg N ha⁻¹. Khursheed and Mahammad (2015) reported that total protein was increased significantly by applying N as urea. These results agreed with those found by Lopez-Bellido *et al.*, 2008 and Giambalvo *et al.*, 2010, due to an increase in nitrogen uptake which consider as a building block in the synthesis of proteins. Woolfolk *et al.* (2002) concluded that nitrogen application near flowering is effective to increase post-flowering nitrogen uptake, grain yield and grain protein content.

The interaction effect of irrigation and nitrogen was significant for grain protein content (%) in both the years and are given in Table 96a for first year (2014-15) and in Table 96b for second year (2015-16). The highest grain protein was given by the treatment combinations of three irrigations (I₃) × three split (N₂) applications of nitrogen which was statistically identical with three irrigations (I₃) × four split (N₃) applications of nitrogen and the lowest value was given by the treatment combinations of rain-fed (I₀) × control (N₀) in both the growing seasons.

4.10.4. Straw protein content

Straw protein content (%) in wheat was significantly influenced by number of irrigations in both the growing seasons and are shown in Table 93a for first year (2014-15) and in Table 93b for second year (2015-16). The total amount of straw protein content (%) increased with increasing irrigation levels in both the years. The highest amount of straw protein content (%) was observed in three irrigations (I₃) which was statistically identical with two irrigations (I₂)

and the lowest value was found in rain-fed (I_0) condition in both the years. Similar result was observed in wheat by Ciobanu *et al.*, 1995 and Rahman 2004.

Straw protein content (%) did not differ significantly due to wheat variety in both the years and are given in Table 94a for first year (2014-15) and in Table 94b for second year (2015-16). Between the two varieties, BARI Gom 24 had higher straw protein content (%) than BARI Gom 26.

The effect of split applications of nitrogen on straw protein content are presented in Table 95a for first year (2014-15) and Table 95b for second year (2015-16). Increasing N rate increased straw N content. The highest straw protein content (%) was recorded in three split (N_2) applications of nitrogen which was statistically similar with four split (N_3) and basal (N_1) application of nitrogen and the lowest value was found in control (N_0) in both the years. Similar findings were also reported in wheat by Rahman (2004). Memon and Jamro (1988) carried out a field experiment as urea was applied in equal split applications and reported wheat seed protein content increased from 8.7% without N to 14.5% with 240 kg N ha⁻¹.

Different treatment combinations of irrigation and nitrogen had significant influence on grain protein content (%) in both the growing seasons and are shown in Table 96a for first year (2014-15) and in Table 96b for second year (2015-16). The highest grain protein content (%) was recorded in the treatment combination of three irrigations (I_3) $\times$ three split (N_2) applications of nitrogen which was statistically identical with $I_3 \times N_3$, $I_3 \times N_1$, $I_2 \times N_1$, $I_2 \times N_2$ and $I_2 \times N_3$ in both the years. The lowest value was found in rain-fed (I_0) $\times$ control (N_0) in both the growing seasons.

4.10.5. N- uptake by grain

The irrigation levels exhibited significant influence on N-uptake by grain in both the growing seasons and are presented in Table 93a for first year (2014-15) and in Table 93b for second year (2015-16). N-uptake by grain increased with increasing irrigation levels in both the years. The highest N-uptake by grain was recorded by three irrigations (I_3) which was at par with two irrigations (I_2) and the lowest value was found in rain-fed (I_0) wheat crops in both the years. Similar result was recorded in wheat by Shen *et al.*, 2001 and Rahman 2004.

There was no significant effect on N-uptake by grain in different wheat variety in both the years and are given in Table 94a for first year (2014-15) and in Table 94b for second year (2015-16). Between the two varieties, BARI Gom 24 had higher N-uptake by grain than BARI Gom 26.

The effects of nitrogen on N-uptake by grain in both the years and is presented in Table 95a for first year (2014-15) and in Table 95b for second year (2015-16). The highest N-uptake by grain was observed in three split (N_2) applications of nitrogen which was statistically identical with four split (N_3) and basal (N_1) application of nitrogen and the lowest value was found in control (N_0) in both the years. Reena *et al.* (2017) stated that increasing trend of total nitrogen uptake was obtained with increasing of nitrogen application. Similar result was reported in wheat by many researchers (Dhuka *et al.*, 1992, Singh and Uttam 1995, Vukovic *et al.*, 2008, Shirazi *et al.*, 2014 and Belete *et al.*, 2018). Rahman *et al.* (2011) reported that three equal split application of nitrogen was effective in increasing N-uptake of wheat. Reena *et al.* (2017) reported that increasing trend of total nitrogen uptake was obtained with increasing rate of nitrogen application. Maiti and Das (2006) also reported that the total N-uptake was directly proportional to total nitrogen rates with three split application. The increases in wheat total N-uptake with application of N-fertilizer have been reported by Eck (1988). Dhuka *et al.* (1992) also stated that N-uptake by grain increased with an increase in N level. Adjetey *et al.* (2001) reported that split application of N increased N-uptake most, when second dose was applied at tillering. Chandurkar *et al.* (2007) observed increased N content and N-uptake in grain and straw of wheat with increasing N fertilizer rates.

N-uptake by grain was significantly influenced by the interaction of irrigation and nitrogen in both the growing seasons and is given in Table 96a for first year (2014-15) and in Table 96b for second year (2015-16). The highest N-uptake by grain was observed in the treatment combination of three irrigations (I_3) $\times$ three splits (N_2) application of nitrogen followed by $I_3 \times N_3$ and $I_2 \times N_2$ and the lowest value was found in rain-fed (I_0) $\times$ control (N_0) in both the growing seasons.

4.10.6. N-uptake by straw

Irrigation treatments had significant effect on N-uptake by straw in both the growing seasons and are presented in Table 93a for first year (2014-15) and in Table 93b for second year (2015-16). The total amount of N-uptake by straw increased with increasing irrigation levels in both the years. The highest amount of N-uptake by straw was recorded in three irrigations (I_3) which was statistically identical with two irrigations (I_2) and the lowest value was found in rain-fed (I_0) condition in both the years. Similar result was recorded in wheat by Shen *et al.*, 2001 and Rahman 2004.

N-uptake by straw was not significant due to variety in both the growing seasons and are shown in Table 94a for first year (2014-15) and in Table 94b for second year (2015-16). Between the two varieties, BARI Gom 24 had higher N-uptake by straw than BARI Gom 26.

The effects of split applications of nitrogen on N-uptake by straw in both the growing seasons and are presented in Table 95a for first year (2014-15) and Table 95b for second year (2015-16). The highest N-uptake by straw was recorded in three split (N_2) applications of nitrogen which was statistically similar with four split (N_3) and basal (N_1) application of nitrogen and the lowest value was obtained in control (N_0) in both the growing seasons. Similar result was reported in wheat by many researchers (Sachdev *et al.*, 1990 and Singh and Uttam 1995). Dhuka *et al.* (1992) stated that N-uptake by straw increased with an increase in N level. Adjetey *et al.* (2001) reported that split application of N increased N-uptake of wheat. Chandurkar *et al.* (2007) determined increased N content and N-uptake in grain and straw of wheat with increasing N fertilizer rates.

The interaction effect of irrigation and nitrogen was significant for N-uptake by straw in both the years and are given in Table 96a for first year (2014-15) and in Table 96b for second year (2015-16). The highest N-uptake by straw was obtained by the treatment combinations of three irrigations (I_3) $\times$ three split (N_2) applications of nitrogen followed by $I_3 \times N_3$ and $I_2 \times N_2$ and the lowest value was found by the treatment combinations of rain-fed (I_0) $\times$ control (N_0) in both the growing seasons.

4.10.7. N use efficiency

N use efficiency differed significantly in the different irrigation treatments in both the growing seasons and is presented in Table 93a for first year (2014-15) and in Table 93b for second year (2015-16). N use efficiency was significantly increased with increasing number of irrigations in both the years. The highest value of N use efficiency was recorded in three irrigations (I_3) which was statistically similar with two irrigations (I_2) followed by one irrigation (I_1) and the lowest value were found in rain-fed (I_0) condition in both the years. Mandic *et al.* (2014) reported that the NUE depends of the water availability and also stated that NUE had lower value when water was a limiting factor.

N use efficiency did not differ significantly due to wheat variety in both the years and are shown in Table 94a for first year (2014-15) and in Table 94b for second year (2015-16). Between the two varieties, BARI Gom 24 had higher nitrogen use efficiency than BARI Gom 26.

N use efficiency was significantly influenced by different split applications of nitrogen in both the growing seasons and is presented in Table 95a for first year (2014-15) and in Table 95b for second year (2015-16). The highest N use efficiency was recorded in three split (N_2) applications of nitrogen which was statistically identical with basal (N_1) application and four split (N_3) applications of nitrogen and the lowest value was found in control (N_0) in both the years. Wuest and Cassman (1992) found that pre-plant nitrogen application may lead to immobilization before plant uptake, greatly affecting nitrogen use efficiency. Mandic *et al.* (2014) reported that NUE significantly increased with increase N fertilization level than in control. Rahimizadeh *et al.* (2010) stated that the lowest NUE of wheat was always associated with the control treatment. Rahman *et al.* (2011) also reported that three equal split application of nitrogen was effective in increasing nitrogen use efficiency of wheat. Similar result was reported in wheat many workers (Rahman *et al.*, 2002, Rahimizadeh *et al.*, 2010, Reena *et al.*, 2017 and Belete *et al.*, 2018).

N use efficiency was significantly influenced by the interaction of irrigation and nitrogen in both the growing seasons and is presented in Table 96a for first year (2014-15) and in Table 96b for second year (2015-16). The highest N use efficiency was recorded in the treatment combination of three irrigations (I_3) $\times$ three split (N_2) applications of nitrogen which was statistically similar with $I_2 \times N_2$ followed by $I_3 \times N_3$ and $I_2 \times N_3$ and the lowest value was found in $I_0 \times N_0$, $I_1 \times N_0$, $I_2 \times N_0$ and $I_3 \times N_0$ in both the growing seasons.

Table 93a: Effect of irrigation on nitrogen content, protein content, nitrogen uptake of grain and straw and nitrogen use efficiency of wheat (2014-2015)

Irrigation	N content (%) in grain	N content (%) in straw	Grain protein content (%)	Straw protein content (%)	N uptake by grain (kg ha ⁻¹)	N uptake by straw (kg ha ⁻¹)	N use efficiency
I ₀	2.124 c	0.366 c	11.881 c	2.285 c	48.901 b	14.370 c	1.972 b
I ₁	2.214 bc	0.415 b	12.409 bc	2.595 b	61.554 b	18.643 b	2.770 b
I ₂	2.292 ab	0.457 a	12.862 ab	2.854 a	88.826 a	26.676 a	6.332 a
I ₃	2.331 a	0.469 a	13.087 a	2.930 a	96.013 a	27.790 a	6.364 a
CV (%)	3.976	1.343	3.976	1.335	0.757	1.492	2.103

In a column, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

Table 93b: Effect of irrigation on nitrogen content, protein content, nitrogen uptake of grain and straw and nitrogen use efficiency of wheat (2015-2016)

Irrigation	N content (%) in grain	N content (%) in straw	Grain protein content (%)	Straw protein content (%)	N uptake by grain (kg ha ⁻¹)	N uptake by straw (kg ha ⁻¹)	N use efficiency
I ₀	2.140 c	0.369 c	11.974 c	2.305 c	49.708 b	14.590 c	1.990 b
I ₁	2.234 bc	0.419 b	12.523 bc	2.618 b	62.647 b	18.887 b	2.795 b
I ₂	2.312 ab	0.461 a	12.982 ab	2.879 a	89.933 a	26.969 a	6.354 a
I ₃	2.351 a	0.473 a	13.209 a	2.955 a	97.111 a	28.060 a	6.380 a
CV (%)	3.978	10.728	3.979	10.747	0.758	1.494	2.109

In a column, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

Table 94a: Effect of variety on nitrogen content, protein content, nitrogen uptake of grain and straw and nitrogen use efficiency of wheat (2014-2015)

Variety	N content (%) in grain	N content (%) in straw	Grain protein content (%)	Straw protein content (%)	N uptake by grain (kg ha ⁻¹)	N uptake by straw (kg ha ⁻¹)	N use efficiency
V ₁	2.268 a	0.428 a	12.723 a	2.674 a	74.504 a	21.914 a	4.412 a
V ₂	2.212 a	0.425 a	12.397 a	2.657 a	73.142 a	21.826 a	4.307 a
CV (%)	3.976	1.343	3.976	1.335	0.757	1.492	2.103

In a column, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

Table 94b: Effect of variety on nitrogen content, protein content, nitrogen uptake of grain and straw and nitrogen use efficiency of wheat (2015-2016)

Variety	N content (%) in grain	N content (%) in straw	Grain protein content (%)	Straw protein content (%)	N uptake by grain (kg ha ⁻¹)	N uptake by straw (kg ha ⁻¹)	N use efficiency
V ₁	2.288 a	0.432 a	12.836 a	2.698 a	75.540 a	22.171 a	4.432 a
V ₂	2.231 a	0.429 a	12.507 a	2.681 a	74.160 a	22.082 a	4.326 a
CV (%)	3.978	10.728	3.979	10.747	0.758	1.494	2.109

In a column, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

Table 95a: Effect of nitrogen on nitrogen content, protein content, nitrogen uptake of grain and straw and nitrogen use efficiency of wheat (2014-2015)

Nitrogen	N content (%) in grain	N content (%) in straw	Grain protein content (%)	Straw protein content (%)	N uptake by grain (kg ha ⁻¹)	N uptake by straw (kg ha ⁻¹)	N use efficiency
N ₀	2.041 b	0.350 b	11.399 b	2.187 b	46.805 b	14.428 b	0.000 b
N ₁	2.292 a	0.448 a	12.861 a	2.797 a	78.985 a	23.645 a	5.166 a
N ₂	2.328 a	0.459 a	13.074 a	2.866 a	86.641 a	25.160 a	6.402 a
N ₃	2.299 a	0.450 a	12.905 a	2.813 a	82.862 a	24.247 a	5.870 a
CV (%)	3.976	1.343	3.976	1.335	0.757	1.492	2.103

In a column, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

Table 95b: Effect of nitrogen on nitrogen content, protein content, nitrogen uptake of grain and straw and nitrogen use efficiency of wheat (2015-2016)

Nitrogen	N content (%) in grain	N content (%) in straw	Grain protein content (%)	Straw protein content (%)	N uptake by grain (kg ha ⁻¹)	N uptake by straw (kg ha ⁻¹)	N use efficiency
N ₀	2.059 b	0.353 b	11.501 b	2.206 b	47.468 b	14.600 b	0.000 b
N ₁	2.311 a	0.452 a	12.975 a	2.822 a	80.080 a	23.921 a	5.189 a
N ₂	2.348 a	0.462 a	13.191 a	2.891 a	87.841 a	25.454 a	6.432 a
N ₃	2.319 a	0.454 a	13.020 a	2.838 a	84.009 a	24.530 a	5.897 a
CV (%)	3.978	10.728	3.979	10.747	0.758	1.494	2.109

In a column, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

Table 96a: Interaction effect of irrigation and nitrogen on nitrogen content, protein content, nitrogen uptake of grain and straw and nitrogen use efficiency of wheat (2014-2015)

Interaction (Irrigation × Nitrogen)	N content (%) in grain	N content (%) in straw	Grain protein content (%)	Straw protein content (%)	N uptake by grain (kg ha ⁻¹)	N uptake by straw (kg ha ⁻¹)	N use efficiency
I ₀ N ₀	1.924 i	0.322 g	10.717 i	2.010 g	35.687 l	11.620 i	0.000 i
I ₀ N ₁	2.160 e-g	0.378 de	12.091 e-g	2.361 de	50.801 j	15.052 g	2.263 h
I ₀ N ₂	2.213 c-e	0.386 d	12.403 c-e	2.410 d	55.593 hi	15.604 g	2.988 f
I ₀ N ₃	2.198 d-f	0.378 de	12.314 d-f	2.360 de	53.522 ij	15.207 g	2.638 g
I ₁ N ₀	2.026 h	0.338 fg	11.313 h	2.109 fg	43.634 k	13.515 h	0.000 i
I ₁ N ₁	2.284 b-d	0.428 c	12.813 b-d	2.676 c	64.756 g	19.307 e	3.104 f
I ₁ N ₂	2.298 bc	0.454 b	12.896 bc	2.834 b	71.108 f	21.492 d	4.280 d
I ₁ N ₃	2.249 cd	0.442 bc	12.613 cd	2.761 bc	66.721 g	20.258 de	3.697 e
I ₂ N ₀	2.092 gh	0.358 ef	11.694 gh	2.235 ef	51.081 i	15.335 g	0.000 i
I ₂ N ₁	2.355 ab	0.490 a	13.228 ab	3.061 a	96.784 e	29.773 c	7.585 c
I ₂ N ₂	2.366 ab	0.491 a	13.294 ab	3.069 a	105.845 c	31.238 ab	9.236 a
I ₂ N ₃	2.356 ab	0.488 a	13.233 ab	3.050 a	101.593 d	30.359 bc	8.506 b
I ₃ N ₀	2.123 fg	0.383 d	11.874 fg	2.394 d	56.819 h	17.242 f	0.000 i
I ₃ N ₁	2.369 ab	0.495 a	13.311 ab	3.092 a	103.602 cd	30.448 bc	7.711 c
I ₃ N ₂	2.436 a	0.504 a	13.704 a	3.151 a	114.017 a	32.307 a	9.104 a
I ₃ N ₃	2.395 a	0.493 a	13.460 a	3.083 a	109.614 b	31.163 ab	8.640 b
CV (%)	3.976	1.343	3.976	1.335	0.757	1.492	2.103

In a column, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

Table 96b: Interaction effect of irrigation and nitrogen on nitrogen content, protein content, nitrogen uptake of grain and straw and nitrogen use efficiency of wheat (2015-2016)

Interaction (Irrigation × Nitrogen)	N content (%) in grain	N content (%) in straw	Grain protein content (%)	Straw protein content (%)	N uptake by grain (kg ha ⁻¹)	N uptake by straw (kg ha ⁻¹)	N use efficiency
I ₀ N ₀	1.938 h	0.324 g	10.801 h	2.028 g	36.276 k	11.797 i	0.000 i
I ₀ N ₁	2.176 ef	0.381 de	12.185 ef	2.382 de	51.640 i	15.281 g	2.283 h
I ₀ N ₂	2.230 c-e	0.389 d	12.499 c-e	2.431 d	56.512 h	15.842 g	3.015 f
I ₀ N ₃	2.214 de	0.381 de	12.410 de	2.381 de	54.406 hi	15.439 g	2.662 g
I ₁ N ₀	2.044 g	0.340 fg	11.417 g	2.128 fg	44.408 j	13.693 h	0.000 i
I ₁ N ₁	2.304 bc	0.432 c	12.931 bc	2.699 c	65.905 g	19.560 e	3.131 f
I ₁ N ₂	2.318 bc	0.457 b	13.015 bc	2.858 b	72.369 f	21.773 d	4.318 d
I ₁ N ₃	2.269 cd	0.446 bc	12.729 cd	2.785 bc	67.905 g	20.523 de	3.730 e
I ₂ N ₀	2.110 fg	0.361 ef	11.803 fg	2.255 ef	51.718 i	15.503 g	0.000 i
I ₂ N ₁	2.376 ab	0.494 a	13.351 ab	3.088 a	97.990 e	30.100 c	7.611 c
I ₂ N ₂	2.387 ab	0.495 a	13.417 ab	3.096 a	107.164 c	31.581 ab	9.268 a
I ₂ N ₃	2.377 ab	0.492 a	13.356 ab	3.077 a	102.859 d	30.693 bc	8.535 b
I ₃ N ₀	2.141 ef	0.386 d	11.985 ef	2.415 d	57.468 h	17.409 f	0.000 i
I ₃ N ₁	2.390 ab	0.499 a	13.434 ab	3.119 a	104.787 cd	30.744 bc	7.730 c
I ₃ N ₂	2.458 a	0.509 a	13.831 a	3.178 a	115.321 a	32.620 a	9.126 a
I ₃ N ₃	2.416 a	0.498 a	13.585 a	3.109 a	110.867 b	31.466 ab	8.662 b
CV (%)	3.978	10.728	3.979	10.747	0.758	1.494	2.109

In a column, means followed by different letter(s) differed significantly by Tukey's test at $P \leq 5\%$ level of probability.

4.11. Cost of production

Cost of production of wheat was measured according to Mian and Bhuiya (1977). The total cost of production of BARI Gom 24 and BARI Gom 26 under present investigation was divided into two major heads of expenditure- (a) input cost and (b) overhead cost. Again the input cost was divided as the non-material input cost such as human and animal labor and the material input cost such as seeds, irrigation water, fertilizers, pesticide and miscellaneous material costs. The overhead cost, which contributes a considerable part of the total cost of production, included the interest on input cost and land use cost.

The cost of production and return of unit plot of wheat (cv.BARI Gom 24 and BARI Gom 26) due to application of irrigation water and nitrogen fertilizer application converted into hectare and discussed below:

4.11.1. Input Cost

Input costs are the costs of using the variable inputs. These costs vary with the level of production. There are some necessary inputs like seed, human labor, fertilizer, irrigation, etc. without these it is not possible to produce agricultural products. These cost items are discussed as follows:

4.11.1.1. Non-material cost

Human labor is the most important input for producing wheat. Labor cost for all treatments is presented in Table 97, 98 and 99. Labor cost excluding irrigation and nitrogen treatments was same, because the same amount taka was charged for other operations (Table 97). Table 97, 98 and 99 reveals that the highest human cost (Tk. 20100) was required in I_3N_3 followed by I_3N_2 (TK. 19800) and I_2N_3 (Tk. 19800) and the lowest cost was required in I_0N_0 of BARI Gom 24 and BARI Gom 26 in both the years.

Table 97: Operation-wise breakup of the labor required per hectare for production of BARI Gom 24 and BARI Gom 26 (Excluding irrigation and nitrogen fertilizer application)

Sl.No.	Production operation	Labor (No.)	Rate (TK.)		Animal labor	Rate (TK.)		Total (TK.)
			Per labor	Total (TK.)		Per animal labor day	Total (TK.)	
1	Land preparation (ploughing and laddering)	5	300	1500	5	200	1000	2500
2	Trimming, spading of corners and removing stubbles	2	300	600				600
3	Seed sowing	2	300	600				600
4	Weeding and thinning	35	300	10500				10500
5	Harvesting, binding and carrying	12	300	3600				3600
6	Bagging and storing of grains	2	300	600				600
Grand total								18400

Table 98: Labor required per hectare for production of BARI Gom 24 and BARI Gom 26 under different irrigation levels

Treatments	Labor (No.)	Rate (TK.) Per labor	Total (TK.)
I ₀	0	0	0
I ₁	1	300	300
I ₂	2	300	600
I ₃	3	300	900

Table 99: Labor required per hectare for production of BARI Gom 24 and BARI Gom 26 under different nitrogen fertilizer treatments

Treatments	Labor (No.)	Rate (TK.) Per labor	Total (TK.)
N ₀	2	300	600
N ₁	3	300	900
N ₂	5	300	1500
N ₃	6	300	1800

4.11.1.2. Material inputs cost

Material inputs cost excluding irrigation cost and nitrogen cost was same, because the same amount Taka was charged for power tiller, thresher, seed and other fertilizers. The operation-wise break-up of the total input cost representing the shares of the individual operation had been presented in Tables 100, 101, 102, 103 and 104. The highest material inputs cost was recorded from the interaction of I_3N_3 , I_3N_2 and I_3N_1 (Tk. 34015) followed by I_2N_3 , I_2N_2 and I_2N_1 (Tk. 31815) and the lowest inputs cost was needed in I_0N_0 for BARI Gom 24 and BARI Gom 26 in both the years.

Power tiller cost

Per hectare power tiller cost for first tillage operation of wheat productions in both the year (2014-2015 and 2015-2016) were estimated at Tk. 2245.00 and Tk.2245.00, respectively.

Table 100: Per hectare power tiller cost (TK.) for producing BARI Gom 24 and BARI Gom 26 in 2014-2015 and in 2015-2016.

Production operation	Cost (TK.)/ha in 2014-2015	Cost (TK.)/ha in 2015-2016
Power tiller	2245.00	2245.00

Cost of thresher

Per hectare thresher cost for threshing wheat in 2014-2015 and 2015-2016 were estimated at TK. 3000.00.

Table 101: Per hectare thresher cost (TK.) for threshing of BARI Gom 24 and BARI Gom 26 in 2014-2015 and in 2015-2016.

Production operation	Cost (TK.)/ha in 2014-2015	Cost (TK.)/ha in 2015-2016
Thresher	3000.00	3000.00

Cost of irrigation

Cost of irrigation water (one time, two times and three times) per hectare land of wheat productions were estimated in 2014-2015 and 2015-2016 at Tk.2200.00, TK. 4400.00 and Tk.6600.00, respectively.

Table 102: Different irrigation levels cost (TK.) for BARI Gom 24 and BARI Gom 26 production in 2014-2015 and in 2015-2016.

Production operation	Cost (TK.)/ha in 2014-2015	Cost (TK.) /ha in 2015-2016
I ₀	0.00	0.00
I ₁	2200.00	2200.00
I ₂	4400.00	4400.00
I ₃	6600.00	6600.00

Cost of seed

Seed is the basic input for crop production. The costs of seed for both wheat varieties were TK. 4800.00 in 2014-2015 and 2015-2016. For two wheat varieties 120 kg seed was required per hectare and the price of seed was Tk. 40.00 per kg.

Cost of nitrogenous fertilizer

Nitrogenous fertilizer cost for per hectare of land of wheat production were estimated in 2014-2015 and 2015-2016 at TK 3840.00

Table 103: Nitrogenous fertilizer cost (TK.) for BARI Gom 24 and BARI Gom 26 production in 2014-2015 and in 2015-2016.

Item	Cost (TK.)/ha in 2014-2015	Cost (TK.)/ha in 2015-2016
Nitrogenous fertilizer(Urea)	3840.00	3840.00

Cost of other fertilizers

Table 104: Different fertilizer cost (TK.) for BARI Gom 24 and BARI Gom 26 production in 2014-2015 and in 2015-2016 (Excluding nitrogenous fertilizer).

Sl.No.	Items	Quantity	Rate	Cost (TK.)
1	TSP	180 kg ha ⁻¹	22 TK.kg ⁻¹	3960.00
2	MoP	110 kg ha ⁻¹	15 TK.kg ⁻¹	1650.00
3	Gypsum	120 kg ha ⁻¹	24 TK.kg ⁻¹	2880.00
4	Zinc sulphate	12 kg ha ⁻¹	120 TK.kg ⁻¹	1440.00
5	Boric acid	6 kg ha ⁻¹	600 TK.kg ⁻¹	3600.00
Total cost				13530.00

4.11.2. Interest on operating cost

Interest on operating cost which includes variable costs in the production of BARI Gom 24 and BARI Gom 26 for a period of 4 months production period. Interest rate of 10 percent per annum for all treatments of both the varieties was considered for calculation. It has been calculated using the following formula:

$$\text{Interest on operating cost} = \frac{\text{operating cost} \times \text{rate of interest} \times \text{time}}{2}$$

4.11.3. Fixed Cost

Fixed costs are those cost which do not change. The land use cost was considered as fixed cost wheat production in this study. The seasonal rental cost of land was treated as land use cost. Land use cost was a fixed cost. Land use cost was amounted to Tk.15000.00 ha⁻¹ for 2014-2015 and 2015-2016 in both the varieties.

4.11.4. Total cost of production

Total cost of production was calculated by adding all costs of variable inputs and fixed inputs. The total cost of production ha⁻¹ and its distribution over different interaction in the study have been shown in Tables 105, 106, 107 and 108. The highest cost of production was needed in I₃N₃ (Tk. 72870.75) followed by I₃N₂ (Tk. 72555.75) and I₃N₁ (Tk. 71925.75) and the lowest value was required in I₀N₀ (Tk. 59703.75) of BARI Gom 24 and BARI Gom 26 in both the years.

Table 105: Total cost of production ha⁻¹ and its distribution over different head of expenditure of two wheat cultivars in different nitrogen treatments under rain-fed condition (I₀)

Head of expenditure	Rain- fed condition (I ₀)							
	BARI Gom 24 (V ₁)				BARI Gom 26 (V ₂)			
	N ₀	N ₁	N ₂	N ₃	N ₀	N ₁	N ₂	N ₃
I. Input cost								
A. Non-material input								
a. Laborer								
-Human	18000	18300	18900	19200	18000	18300	18900	19200
-Animal	1000	1000	1000	1000	1000	1000	1000	1000
Non-material input cost	19000	19300	19900	20200	19000	19300	19900	20200
B. Material input								
b. power tiller	2245	2245	2245	2245	2245	2245	2245	2245
c. Seed	4800	4800	4800	4800	4800	4800	4800	4800
d. Irrigation	0	0	0	0	0	0	0	0
e. Fertilizer	13530	17370	17370	17370	13530	17370	17370	17370
f. Thresher	3000	3000	3000	3000	3000	3000	3000	3000
Material input cost	23575	27415	27415	27415	23575	27415	27415	27415
Total input cost(IC)	42575	46715	47315	47615	42575	46715	47315	47615
II. Overhead cost								
g. Interest on input cost	1419	1557	1577	1587	1419	1557	1577	1587
h. Rental cost of land	15000	15000	15000	15000	15000	15000	15000	15000
i. Common cost	710	779	789	794	710	779	789	794
Total overhead cost(OC)	17129	17336	17366	17381	17129	17336	17366	17381
Total cost of production(TCP)	59704	64051	64681	64996	59704	64051	64681	64996

Table 106: Total cost of production ha⁻¹ and its distribution over different head of expenditure of two wheat cultivars in different nitrogen treatments under one irrigation treatment (I₁)

Head of expenditure	One irrigation (I ₁)							
	BARI Gom 24 (V ₁)				BARI Gom 26 (V ₂)			
	N ₀	N ₁	N ₂	N ₃	N ₀	N ₁	N ₂	N ₃
I. Input cost								
A. Non-material input								
a. Laborer								
-Human	18300	18600	19200	19500	18300	18600	19200	19500
-Animal	1000	1000	1000	1000	1000	1000	1000	1000
Non-material input cost	19300	19600	20200	20500	19300	19600	20200	20500
B. Material input								
b. power tiller	2245	2245	2245	2245	2245	2245	2245	2245
c. Seed	4800	4800	4800	4800	4800	4800	4800	4800
d. Irrigation	2200	2200	2200	2200	2200	2200	2200	2200
e. Fertilizer	13530	17370	17370	17370	13530	17370	17370	17370
f. Thresher	3000	3000	3000	3000	3000	3000	3000	3000
Material input cost	25775	29615	29615	29615	25775	29615	29615	29615
Total input cost(IC)	1503	1641	1661	1671	1503	1641	1661	1671
II. Overhead cost								
g. Interest on input cost	1503	1641	1661	1671	1503	1641	1661	1671
h. Rental cost of land	15000	15000	15000	15000	15000	15000	15000	15000
i. Common cost	751	820	830	835	751	820	830	835
Total overhead cost(OC)	17254	17461	17491	17506	17254	17461	17491	17506
Total cost of production(TCP)	62329	66676	67306	67621	62329	66676	67306	67621

Table 107: Total cost of production ha⁻¹ and its distribution over different head of expenditure of two wheat cultivars in different nitrogen treatments under two irrigations (I₂)

Head of expenditure	Two irrigations (I ₂)							
	BARI Gom 24 (V ₁)				BARI Gom 26 (V ₂)			
	N ₀	N ₁	N ₂	N ₃	N ₀	N ₁	N ₂	N ₃
I. Input cost								
A. Non-material input								
a. Laborer								
-Human	18600	18900	19500	19800	18600	18900	19500	19800
-Animal	1000	1000	1000	1000	1000	1000	1000	1000
Non-material input cost	19600	19900	20500	20800	19600	19900	20500	20800
B. Material input								
b. power tiller	2245	2245	2245	2245	2245	2245	2245	2245
c. Seed	4800	4800	4800	4800	4800	4800	4800	4800
d. Irrigation	4400	4400	4400	4400	4400	4400	4400	4400
e. Fertilizer	13530	17370	17370	17370	13530	17370	17370	17370
f. Thresher	3000	3000	3000	3000	3000	3000	3000	3000
Material input cost	27975	31815	31815	31815	27975	31815	31815	31815
Total input cost(IC)	47575	51715	52315	52615	47575	51715	52315	52615
II. Overhead cost								
g. Interest on input cost	1586	1724	1744	1754	1586	1724	1744	1754
h. Rental cost of land	15000	15000	15000	15000	15000	15000	15000	15000
i. Common cost	793	862	872	877	793	862	872	877
Total overhead cost(OC)	17379	17586	17616	17631	17379	17586	17616	17631
Total cost of production(TCP)	64954	69301	69931	70246	64954	69301	69931	70246

Table 108: Total cost of production ha⁻¹ and its distribution over different head of expenditure of two wheat cultivars in different nitrogen treatments under three irrigations (I₃)

Head of expenditure	Three irrigations (I ₃)							
	BARI Gom 24 (V ₁)				BARI Gom 26 (V ₂)			
	N ₀	N ₁	N ₂	N ₃	N ₀	N ₁	N ₂	N ₃
I. Input cost								
A. Non-material input								
a. Laborer								
-Human	18900	19200	19800	20100	18900	19200	19800	20100
-Animal	1000	1000	1000	1000	1000	1000	1000	1000
Non-material input cost	19900	20200	20800	21100	19900	20200	20800	21100
B. Material input								
b. power tiller	2245	2245	2245	2245	2245	2245	2245	2245
c. Seed	4800	4800	4800	4800	4800	4800	4800	4800
d. Irrigation	6600	6600	6600	6600	6600	6600	6600	6600
e. Fertilizer	13530	17370	17370	17370	13530	17370	17370	17370
f. Thresher	3000	3000	3000	3000	3000	3000	3000	3000
Material input cost	30175	34015	34015	34015	30175	34015	34015	34015
Total input cost(IC)	50075	54215	54815	55115	50075	54215	54815	55115
II. Overhead cost								
g. Interest on input cost	1669	1807	1827	1837	1669	1807	1827	1837
h. Rental cost of land	15000	15000	15000	15000	15000	15000	15000	15000
i. Common cost	835	904	914	919	835	904	914	919
Total overhead cost(OC)	17504	17711	17741	17756	17504	17711	17741	17756
Total cost of production(TCP)	67579	71926	72556	72871	67579	71926	72556	72871

4.11.5. Gross income

Per hectare gross income were calculated by multiplying the total amount of product and by-product with their respective local market prices. Per hectare gross income is presented in Tables 109, 110, 111 and 112. The highest gross income was recorded from the interaction of V₁I₃N₂ (Tk. 132544) followed by V₂I₃N₂ (Tk. 131050), V₁I₃N₃ (Tk. 129245), V₂I₃N₃ (Tk. 128704), V₁I₃N₁ (Tk. 123774) and V₂I₃N₁ (Tk. 122887) and the lowest gross income was obtained in V₁I₀N₀ (Tk. 52298). Thus it was clear that three irrigated BARI Gom 24 with three split applications of nitrogen earned highest gross income than other treatment combinations.

4.11.6. Net income

Net return is a useful tool to evaluate the production profitability. It was calculated by deducting total cost from total income. Per hectare net income was presented in Tables 109, 110, 111 and 112. The highest net income was earned from the interaction of $V_1I_3N_2$ (Tk. 59988) followed by $V_2I_3N_2$ (Tk. 58494), $V_2I_2N_2$ (Tk. 56704), $V_1I_3N_3$ (Tk. 56374), $V_1I_2N_2$ (Tk. 55922) and $V_2I_3N_3$ (Tk. 55833) and the lowest net income was obtained in $V_1I_0N_0$ (Tk. -7406) followed by $V_2I_0N_0$ (Tk. -5361) and $V_1I_1N_0$ (Tk. -1642).

4.11.7. Benefit- Cost Ratio

Benefit -cost ratio (BCR) was calculated by dividing gross income by total cost. Benefit-cost ratio of different irrigation and nitrogen treatments is shown in Tables 109, 110, 111 and 112. Tables 109, 110, 111 and 112 showed that the highest BCR was found from the interaction of $V_1I_3N_2$ (1.83) followed by $V_2I_3N_2$ (1.81), $V_2I_2N_2$ (1.81), $V_1I_2N_2$ (1.80), $V_1I_3N_3$ (1.77) and $V_2I_3N_3$ (1.77) and the lowest BCR was recorded in $V_1I_0N_0$ (0.88) followed by $V_2I_0N_0$ (0.91) and $V_1I_1N_0$ (0.97). In other words, the highest returns from each Taka of investment were obtained in $V_1I_3N_2$ (0.83) followed by $V_2I_3N_2$ (0.81), $V_2I_2N_2$ (0.81), $V_1I_2N_2$ (0.80), $V_1I_3N_3$ (0.77) and $V_2I_3N_3$ (0.77) and the lowest returns from each Taka of investment was found in $V_1I_0N_0$ (-0.12) followed by $V_2I_0N_0$ (-0.09) and $V_1I_1N_0$ (-0.03). So, among the interactions, it was revealed from the study that production of three irrigated BARI Gom 24 under three split application of nitrogen was found to be the most profitable.

It was revealed from the study that three irrigations were found to be more profitable for wheat production than other irrigation treatments. In case of nitrogen treatments, three split applications of nitrogen had more benefits than other application of nitrogen. Comparative study between different irrigation levels with different split application of nitrogen and variety, it was revealed that combinations of three irrigations (I_3), BARI Gom 24 (V_1) and three split (N_2) applications of nitrogen was more profitable in view of water and nitrogen fertilizer economy.

Table 109: Per hectare production cost and returns of BARI Gom 24 and BARI Gom 26 of different nitrogen treatments under rain-fed condition

Particulars	Rain- fed condition (I ₀)							
	BARI Gom 24 (V ₁)				BARI Gom 26 (V ₂)			
	N ₀	N ₁	N ₂	N ₃	N ₀	N ₁	N ₂	N ₃
I. Total cost of production(TK.ha ⁻¹)	59704	64051	64681	64996	59704	64051	64681	64996
II. Output (yield)								
a. Product (grain) (t ha ⁻¹)	1.819	2.324	2.481	2.419	1.891	2.382	2.544	2.451
b. By product (straw)(t ha ⁻¹)	3.557	3.964	3.999	3.998	3.673	4.007	4.101	4.06
III. Gross income (TK. ha ⁻¹)								
a. Product (grain)	48741	62272	66479	64818	50670	63826	68167	65675
b. By product (straw)	3557	3964	3999	3998	3673	4007	4101	4060
Gross income	52298	66236	70478	68816	54343	67833	72268	69735
IV.Net income (+) or loss (-) (TK. ha ⁻¹)	-7406	2185	5797	3820	-5361	3783	7587	4739
V. a.Net income (+) or loss(-) TK./invested(TK.)	-0.12	0.03	0.09	0.06	-0.09	0.06	0.12	0.07
b. Benefit- cost ratio (BCR)	0.88	1.03	1.09	1.06	0.91	1.06	1.12	1.07

Table 110: Per hectare production cost and returns of BARI Gom 24 and BARI Gom 26 of different nitrogen treatments under one irrigation

Particulars	One irrigation (I ₁)							
	BARI Gom 24 (V ₁)				BARI Gom 26 (V ₂)			
	N ₀	N ₁	N ₂	N ₃	N ₀	N ₁	N ₂	N ₃
I. Total cost of production (TK.ha ⁻¹)	62329	66676	67306	67621	62329	66676	67306	67621
II. Output (yield)								
a. Product (grain) (t ha ⁻¹)	2.117	2.815	3.079	2.947	2.19	2.857	3.11	2.986
b. By product (straw)(t ha ⁻¹)	3.961	4.505	4.728	4.566	4.051	4.516	4.753	4.606
III. Gross income (TK. ha ⁻¹)								
a. Product (grain)	56726	75429	82503	78966	58682	76554	83333	80011
b. By product (straw)	3961	4505	4728	4566	4051	4516	4753	4606
Gross income	60687	79934	87231	83532	62733	81070	88086	84617
IV. Net income (+) or loss (-) (TK. ha ⁻¹)	-1642	13258	19925	15911	404	14394	20781	16996
V. a. Net income (+) or loss(-) TK./invested(TK.)	-0.03	0.20	0.30	0.24	0.01	0.22	0.31	0.25
b. Benefit- cost ratio (BCR)	0.97	1.20	1.30	1.24	1.01	1.22	1.31	1.25

Table 111: Per hectare production cost and returns of BARI Gom 24 and BARI Gom 26 of different nitrogen treatments under two irrigations

Particulars	Two irrigations (I ₂)							
	BARI Gom 24 (V ₁)				BARI Gom 26 (V ₂)			
	N ₀	N ₁	N ₂	N ₃	N ₀	N ₁	N ₂	N ₃
I. Total cost of production (TK.ha ⁻¹)	64954	69301	69931	70246	64954	69301	69931	70246
II. Output (yield)								
a. Product (grain) (t ha ⁻¹)	2.424	4.092	4.458	4.292	2.46	4.129	4.49	4.335
b. By product (straw)(t ha ⁻¹)	4.264	6.121	6.399	6.259	4.313	6.037	6.324	6.185
III. Gross income (TK. ha ⁻¹)								
a. Product (grain)	649526	109646	119453	115005	659169	110638	120311	116158
b. By product (straw)	4264	6121	6399	6259	4313	6037	6324	6185
Gross income	69216	115767	125852	121264	70229	116675	126635	122343
IV.Net income (+) or loss (-) (TK. ha ⁻¹)	4262	46467	55922	51019	5276	47374	56704	52097
V. a.Net income (+) or loss(-) TK./invested(TK.)	0.07	0.67	0.80	0.73	0.08	0.68	0.81	0.74
b. Benefit- cost ratio (BCR)	1.07	1.67	1.80	1.73	1.08	1.68	1.81	1.74

Table 112: Per hectare production cost and returns of BARI Gom 24 and BARI Gom 26 of different nitrogen treatments under three irrigations

Particulars	Three irrigations (I ₃)							
	BARI Gom 24 (V ₁)				BARI Gom 26 (V ₂)			
	N ₀	N ₁	N ₂	N ₃	N ₀	N ₁	N ₂	N ₃
I. Total cost of production (TK.ha ⁻¹)	67579	71926	72556	72871	67579	71926	72556	72871
II. Output (yield)								
a. Product (grain) (t ha ⁻¹)	2.659	4.388	4.705	4.586	2.694	4.358	4.654	4.569
b. By product (straw)(t ha ⁻¹)	4.471	6.196	6.472	6.362	4.532	6.113	6.345	6.276
III. Gross income (TK. ha ⁻¹)								
a. Product (grain)	71249	117578	126072	122883	72186	116774	124705	122428
b. By product (straw)	4471	6196	6472	6362	4532	6113	6345	6276
Gross income	75720	123774	132544	129245	76718	122887	131050	128704
IV. Net income (+) or loss (-) (TK. ha ⁻¹)	8141	51848	59988	56374	9139	50961	58498	55833
V. a. Net income (+) or loss(-) TK./invested(TK.)	0.12	0.72	0.83	0.77	0.14	0.71	0.81	0.77
b. Benefit- cost ratio (BCR)	1.12	1.72	1.83	1.77	1.14	1.71	1.81	1.77

CHAPTER 5

SUMMARY AND CONCLUSION

The experiment was conducted at the research farm and laboratory of Crop Physiology and Ecology Department, Hajee Mohammad Danesh Science and Technology University, Dinajpur, Bangladesh in 2014 - 2015 and 2015 - 2016 to study the morpho-physiological parameters, phenological stages, water relations, chlorophyll content, proline accumulation, nitrogen uptake, protein content, N use efficiency, yield and yield contributing characters of wheat. Benefit-cost ratio was calculated for cultivation of two varieties. Four levels of irrigations (i) I₀- Rain-fed condition (control) (ii) I₁- One irrigation (30 mm) (iii) I₂- Two irrigations (30+30 =60 mm) and (iv) I₃- Three irrigations (30+30+30 =90 mm) and four split application of nitrogen were (i) N₀- control (no nitrogen) (ii) N₁- total nitrogen at basal dose (iii) N₂- one third of the N fertilizer was applied at basal dose, one third of the N fertilizer was applied at crown root initiation stage and the rest was applied at maximum tillering stage and (iv) N₃- one fourth of the N fertilizer was applied at basal dose, one fourth of the N fertilizer was applied at crown root initiation stage, one fourth was applied at maximum tillering stage and the rest was applied at heading stage. Two wheat varieties, namely, BARI Gom 24 and BARI Gom 26 were tested for the above mentioned parameters. The experiment was laid out in a split-split plot design with 3 replications.

Irrigation treatments had significant effect on all growth parameters in both the years. Three irrigations produced the highest plant height, tillers plant⁻¹, total dry matter, leaf area index, crop growth rate, net assimilation rate, relative leaf growth rate and leaf weight ratio which was statistically similar with two irrigations most of the growth parameters and the lowest values was observed in rain-fed condition in both the growing seasons. Relative growth rate fluctuated due to irrigations. At every stages of plant growth, the highest leaf area ratio and specific leaf area were observed in rain-fed crop. With some exceptions, varieties had no significant effect on all growth parameters in both the years. Growth parameters were significantly influenced by split applications of nitrogen in both the growing seasons. Among the nitrogen treatments, three split applications of nitrogen gave the highest plant height, tillers plant⁻¹, TDM, LAI, CGR, NAR and RLGR in both the years which was statistically similar with four split applications of nitrogen in many cases. The highest LWR were observed in control. RGR, LAR and SLA fluctuated due to split applications of nitrogen. In

every case plants growing with nitrogen fertilizer produced higher LAR and SLA than control.

Number of irrigations showed significant effect on days needed to reach different phenological stages in both the years. The plants grown in three irrigations condition needed the highest days for booting, heading, anthesis and physiological maturity which was statistically similar with two irrigations in both the years. The rain-fed plants needed the lowest days for attaining different phenological stages. Varieties had no significant effects on days needed for different phenological stages. Between the two varieties, BARI Gom 26 needed more days for attaining different phenological stages. Days needed for different phenological stages were significant due to split applications of nitrogen in both the years. In every case, the number of days required for attaining different phenological stages was higher for nitrogen application than over the control.

During booting, heading, anthesis and at physiological maturity, the highest plant height, leaf dry weight, stem dry weight, spike dry weight, total dry weight and leaf area were observed in three irrigations which was statistically at par with two irrigations and the lowest values were found in rain-fed condition. With a few exceptions, plant height, leaf dry weight, stem dry weight, spike dry weight, total dry weight and leaf area were not significant due to varieties in both the years but BARI Gom 24 had higher values than BARI Gom 26. Nitrogen treatments had significant effect on plant height, leaf dry weight, stem dry weight, spike dry weight, total dry weight and leaf area in both the growing seasons. Three split applications of nitrogen produced the highest plant height, leaf dry weight, stem dry weight, spike dry weight, total dry weight and leaf area which was statistically similar with four split applications of nitrogen followed by basal applications of nitrogen and control produced the lowest values.

The highest moisture retention capacity and relative leaf water content of the flag leaf were recorded in three irrigated plants followed by two and one irrigations and the lowest was observed in rain-fed plants. Moisture retention capacity and relative leaf water content did not differ significantly due to varieties in both the years. Between the two varieties, BARI Gom 24 had higher MRC than BARI Gom 26. The highest MRC was recorded in four split applications of nitrogen which was statistically similar with three split and basal applications of nitrogen and the lowest was in control. Three split applications of nitrogen produced the highest RLWC which was statistically identical with four split applications of nitrogen in both the growing seasons.

Irrigation treatments had significant effect on chlorophyll content and proline accumulation in both the years. The leaf of three irrigated plants contained the highest chlorophyll a, chlorophyll b and total chlorophyll which were statistically similar with two irrigations in both the years. The highest proline accumulation was observed in rain-fed crops and the least amount of proline was accumulated in three irrigated plants. BARI Gom 26 contained higher chlorophyll and proline accumulation than BARI Gom 24. Chlorophyll and proline varied significantly due to split applications of nitrogen in both the growing seasons. Four split applications of nitrogen contained the highest chlorophyll which was statistically similar with three split applications of nitrogen. The highest proline accumulation was recorded in control and the least amount of proline was accumulated in four split applications of nitrogen. Chlorophyll a : b did not differ due to irrigation and nitrogen .

The highest number of spikelets spike⁻¹, number of grains spike⁻¹, dry weight of spike, dry weight grain⁻¹ and grain growth rate were observed in three irrigation treatments at different days after anthesis which was statistically identical with two irrigations and followed one irrigations. The lowest values were found in rain-fed conditions. Between the two varieties, BARI Gom 24 produced higher number of spikelets spike⁻¹, number of grains spike⁻¹, dry weight of spike, dry weight grain⁻¹ and grain growth rate than BARI Gom 26 at different DAA. Three split applications of nitrogen produced the highest number of spikelets spike⁻¹, number of grains spike⁻¹, dry weight of spike, dry weight of grains and grain growth rate which was statistically similar with four split applications of nitrogen and the control produced the lowest values.

All the yield components i.e., plant height, effective tillers plant⁻¹, spike length, extrusion length, fertile spikelets, 1000-grain weight, grain yield, straw yield, biological yield and harvest index were significantly influenced by different irrigations, varieties and different split applications of nitrogen. Three irrigations produced the highest yield parameters and also grain and straw yield which was statistically similar with two irrigations and the lowest values were found in rain-fed condition. BARI Gom 24 produced higher yield and yield components but BARI Gom 26 produced higher effective tillers plant⁻¹. The highest plant height, effective tillers plant⁻¹, spike length, extrusion length, fertile spikelets, 1000-grain weight, grain yield, straw yield, biological yield and harvest index were observed in three split applications of nitrogen which was statistically similar with four split applications of nitrogen in both the years. The lowest values were found in control (no nitrogen application).

Grain yield was positively correlated with plant height, effective tillers plant⁻¹, spike length, extrusion length, fertile spikelets, 1000-grain weight, grain yield, straw yield, biological yield and harvest index in both the years. Grain yield was negatively correlated with infertile spikelets spike⁻¹.

The highest consumptive use of water was recorded in three irrigated plants and the lowest value was obtained in rain-fed crops while the highest water use efficiency was recorded in rain-fed plants followed by one and two irrigations. Consumptive use of water and water use efficiency did not differ significantly due to varieties in both the years. The CUW did not vary significantly due to nitrogen but a little bit higher CUW was recorded in four split applications of nitrogen. The highest WUE was observed in three split applications of nitrogen which was statistically similar with four split and basal applications of nitrogen.

Irrigation had significant effect on nitrogen and protein content (%) in grain and straw, nitrogen uptake by grain and straw and N use efficiency in both the growing seasons. The highest nitrogen and protein content in grain and straw, nitrogen uptake by grain and straw and N use efficiency were obtained in three irrigations which were statistically similar to two irrigations followed by one irrigation. N-uptake increased with the increase of irrigation levels. The lowest results were found in rain-fed condition. Nitrogen content, protein content and nitrogen uptake by grain and straw and N use efficiency did not differ significantly due to varieties in both the years. Between the two varieties, BARI Gom 24 showed superiority over BARI Gom 26. The highest nitrogen content, protein content, N-uptake by grain and straw and N use efficiency were observed in three split applications of nitrogen which was statistically similar to four split and basal applications of nitrogen and the lowest values were found in control.

The highest benefit-cost ratio was found from BARI Gom 24 with three irrigations and three split applications of nitrogen followed by BARI Gom 26 with three irrigations and three split applications of nitrogen and the lowest BCR was recorded in BARI Gom 24 with rain-fed condition and control. It was revealed from the study that three irrigations were found to be more profitable for wheat production than other irrigation treatments and three split applications of nitrogen had more benefits than other application of nitrogen.

Based on the findings of the experiments the following conclusions may be made:

1. Almost all of the growth, phenology, yield and yield contributing characters are affected by different irrigation and split applications of nitrogen. Among the treatments three irrigation and three split applications of nitrogen shows the best performance.
2. Irrigation frequencies, varieties and split applications of nitrogen were found to be responsive to leaf biochemical characters, nitrogen uptake, N use efficiency and water use of wheat. The variety BARI Gom 24 revealed the best performance almost all parameters with three irrigation and three split applications of nitrogen over BARI Gom 26.
3. BARI Gom 24 with three irrigation and three split applications of nitrogen were found to be more profitable for wheat production.

The experiment may be repeated for on farm trails at different agro-ecological regions of Bangladesh to confirm the findings of the present experiment.

CHAPTER 6

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CHAPTER 7

APPENDICES

Appendix I: Characteristics of soil of the experimental site

General characters	Description	
Location	Research field of Crop Physiology and Ecology, HSTU, Dinajpur.	
AEZ	Old Himalayan Piedmont Plain (AEZ-1)	
General Soil type	Non-Calcareous Brown Floodplain Soil	
Parent material	Piedmont alluvium	
Soil series	Ranishankail	
Drainage	Moderately well drained	
Flood level	Above flood level	
Topography	High land	
Physical characteristics	Value	
Bulk density (g cm ⁻³)	0.86-1.07	
Sand (2-0.02mm)	60.0	
Silt (0.02-0.002mm)	27.0	
Clay (< 0.002mm)	13.0	
Textural class	Sandy loam	
Chemical characteristics	Content	Interpretation
pH	5.40-5.50	Moderately acidic
Organic carbon (%)	0.69	Low
Organic matter (%)	1.19	Low
CEC (meq/100g soil)	5.60	Low
Total N (%)	0.07	Very low
Available P (ppm)	16.75	Medium
Exchangeable K (meq/100g soil)	0.17	Medium low

Source: Analysis of initial soil samples was done in SRDI, Dinajpur, Bangladesh.

Appendix II: Monthly record of air temperature, rainfall, humidity and sunshine hour during the period from November 2014 to April 2015 and November 2015 to April 2016.

(2014-2015)

Month	Air temperature monthly mean (°C)			Monthly total rainfall (mm)	Average monthly humidity (%)	Sunshine in hour day
	Maximum	Minimum	Average			
November	29.43	16.15	22.79	0	81	8.9
December	24.13	12.1	18.11	0	85	7.2
January	22.9	10.48	16.69	24	86	6.8
February	26.9	13.4	20.15	0	80	7.6
March	30.58	16.68	23.63	25.5	74	6.7
April	31.15	20.08	25.61	0	75	9.8
Average			21.16	Total=49.5	80.18	7.83

(2015-2016)

Month	Air temperature monthly mean (°C)			Monthly total rainfall(mm)	Average monthly humidity (%)	Sunshine in hour day
	Maximum	Minimum	Average			
November	29.95	15.55	22.75	0	82	9.7
December	24.53	10.93	17.73	0	84	6.5
January	23.45	9.15	16.3	10	84	7.6
February	28.03	12.85	20.44	0	79	7.4
March	32.05	17.45	24.75	68	74	8.6
April	34.15	21.55	27.85	4	75	8.4
Average			21.64	Total=82	79.63	6.03

Source: Bangladesh Wheat and Maize Research institute, Nashipur, Dinajpur, Bangladesh.