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EFFECT OF NITROGEN AND WATER USE ON YIELD AND STORABILITY OF ONION

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Abstract

A Field experiment was conducted at Regional Spices Research Centre, BARI, Gazipur and Spices Research Sub-Centre, BARI, Lalmonirhat to find out the water and nitrogen use efficiency of onion (*Allium cepa* L.) as influence by different levels of soil moisture regimes and nitrogen doses during *rabi* season of 2020-2021. The experiment was designed in Factorial Randomized Complete Block Design having three replications. The treatment composed of three soil moisture regiems (10%, 20% and 30% depletion of soil moisture over field capacity) and three nitrogen doses (150, 100 and 75 kg ha^{-1}). The individual as well as interaction effect of soil moisture and nitrogen levels showed significant effect on yield and yield contributing parameters, storability, nitrogen and water use efficiency except the TSS of onion. The highest bulb yield (21.49 t ha^{-1} in Gazipur & 22.79 t ha^{-1} in Lalmonirhat), marketable bulb yield (18.0 t ha^{-1} in Gazipur & 20.0 t ha^{-1} in Lalmonirhat), harvest index (598.0% in Gazipur & 607.9% in Lalmonirhat) were recorded when the crop irrigated at 10% depletion of field capacity and plant supplied with 100kg Nha^{-1}. Similarly, the maximum nitrogen use efficiency (54.74% in Gazipur & 61.38% in Lalmonirhat) and the maximum water use efficiency (105.76 kg ha^{-1} mm^{-1} in Gazipur & 108.06 kg ha^{-1} mm^{-1} in Lalmonirhat) were also observed from the above mentioned treatment combinations. Total PLW was higher (16.3% in Gazipur and 21.1% in Lalmonirhat) with irrigation was given applied at 10% depletion of field capacity and application of 150 kg N ha^{-1} during 120 days of storage.

Keywords: Onion, irrigation, nitrogen & water use efficiency and shelf-life.

Introduction

The popular spices crop, onion (*Allium cepa* L.) originated in Central Asia (Afghanistan, Iran and Pakistan), having remarkable medicinal and nutritional properties. The immature and mature bulbs, leaves and often inflorescences are consumed as spices and vegetables in all clans of people in Bangladesh (Yousuf *et al*., 2013). It ranks first in production among the spice crops grown in the country, covering 1.85 lakh hectares of land and produced 19.54 lakh Metric tons bulbs with a productivity of 10.56 t ha^{-1} (BBS, 2021), which is lower in comparison to the world average of 19.7 t ha^{-1}. Onion as fibrous and shallow rooted bulb crop, mostly cultivated during winter season and dormant bulbs are stored for year round

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consumption, except summer onion which is consumed immediate after harvest. Irrigation is indispensable in winter crops due to very little or no precipitation. Water is the most important natural resource especially for crops grown in winter and dry summer season. The soil moisture as natural solvent provides mobility or availability of soil nutrients for plants. Maintaining optimum soil moisture level in whole growing season of onion is elementary. On the other hand, nitrogen as a major constituents of chlorophyll, amino acids, proteins and nucleic acids, the increase in which improved photosynthesis leading to formation of protoplasm and new cells encouragement for growth, development and storability (Bangali *et al*., 2012 and Walle *et al.*, 2018). But farmers are unaware of soil-water-nitrogen-plant dynamics, especially the irrigation and nitrogen to crop needs (Tolossa, 2021 and Gebregwergis *et al.*, 2016). Water and nitrogen are two factors which, with optimum application, increase bulb yield and storability and, if left unchecked, caused huge yield reduction (Kumara *et al*., 2018). Moreover, Kumar *et al.* (2007) reported that the growth and yield parameters such as plant height, number of leaves per plant, biomass, individual bulb weight and bulb yield increased significantly with appropriate irrigation frequencies and nitrogen doses. Study showed that onion grown under water stress and nitrogen deficient condition resulted in bulb rots and early sprouting than anticipated during storage (Fatideh and Asil, 2012). Therefore, judicious application of irrigation and nitrogen fertilizer is of great concern in many parts of the world, like Bangladesh. An excessive use of nitrogen tends to promote severe environmental crisis like land & soil health degradation, eutrophication, cancer and blue baby syndrome. The aim of new agricultural strategy is to maximize crop production by utilizing of minimum resources like land, labor, fertilizers and water. Hence, the present study was undertaken to find out the optimum soil moisture level and nitrogen dose for higher bulb yield, longer storability and to assess nitrogen & water use efficiency of onion in sub-tropical climatic condition of Bangladesh.

Materials and Methods

The present investigation was conducted at the research fields of Regional Spices Research Center, BARI, Gazipur and Spices Research Sub-Centre, BARI, Lalmonirhat during *rabi* season of 2020-2021. The treatment comprises of three soil moisture regimes (Irrigation at 10%, 20% and 30% depletion of field capacity) with three levels of nitrogen *i.e.*, 150 (N_1), 100 (N_2) and 75 (N_3) kg ha^{-1}. The experiment was laid out in Factorial Randomized Complete Block Design with three replications**.** The test crop was onion cv. BARI Piaz-4. Seeds were soaked in water for 12 hours and treated with Autostin (*Carbendazim*) @ 2 g kg^{-1} before sowing to control primary seed-borne diseases. The seeds were sown @ 30 g per seed bed (3m x 1m) on 01 November 2020. Healthy seedlings of 40 days were transplanted into the main field maintaining10cm x10cm spacing on 11 December 2020. The unit plot size was 3.0 m x 1.2 m with 30 cm deck around the plot. Cowdung was applied @ 5 t ha^{-1} and other chemical fertilizers such as P, K, S, Zn and B @ 50, 100, 30, 3.5 and 1.5 kg ha^{-1} were applied as basal before final land preparation. Nitrogen was applied at two equal splits whereas, the 1^{st} split was applied at 25 days after transplanting (DAT) and the second at 50 DAT. The intercultural operations like hand weeding was done thrice to control weed, spraying of Ridomil Gold (*Mancozeb* + *Metalaxyl*), Ruvral (*Iprodione*) @ 2.5 g l^{-1} in alternation with Admire (*Imidacloprid*) @ 2.0 m l^{-1} at 12 days interval for controlling disease and insect pest. The bulbs were harvested 10 days after 80% neck fall on 28 March 2021 in both locations. Data on plant height, number of leaves per plant, neck thickness, days to maturity, bulb size, individual bulb weight and bulb yield were recorded for each treatment from randomly selected 10 plants before harvest. The harvested bulbs were cured for three days in a well aerated shady place to make the bulb firm, dried and colored. Marketable bulb yield was determined by discarding bulb size smaller than 1.5 cm in diameter, injured, thick necked, bolted and rotten to total number of normal bulbs per plot. To enhance the shelf-life after curing, bulbs were cut at 5-7 cm above neck region for storing. Soils from the experimental fields were collected before final land preparation for estimating initial nutrient status and for calculating post-harvest nutrient status of soil. The soil samples were collected from each & every treatment immediately after harvest. The physiography and physico-chemical properties of soil in the experimental sites are described in Table 1a and 1b. About 10 kg of cured bulbs were stored in a plastic rack at room temperature to observe shelf-life. The data on physiological loss in weight were recorded at 30 days interval up to 120 days of storage. After harvesting 10 (ten) selected onion plants from each plot were uprooted, air-dried in the laboratory and finally oven-dried for 72 hours at 65^0C to estimate dry matter production. The dry matter was calculated by the following formula:

$$DM = [\{(DY / 10) \times NP\} \times 10000)]/1000$$

Where,

DM = Dry matter (kg ha^{-1})

DY = Total dry matter yield of 10 plants per plot (g)

NP = Total number of plants per plot

For measuring the TSS, bulb tissue (20.0g) was homogenized in a blender and centrifuged for 20 min at 12000 rpm under 4^0C, the supernatant was analyzed at room temperature with a hand refractometer, expressed as ^{0}Brix.

Harvest index was calculated by the following formula:

$$HI = (EY / BY) \times 100$$

Where,

HI = Harvest index (%)

EY = Marketable bulb yield (kg)

BY = Biological yield (kg)

N uptake from the soil was calculated by using the formula:

N uptake = (A x Y) / 100

Where,

A = N content of plant (%)

Y = Total dry matter production (kg ha^{-1})

N use efficiency was calculated by using following formula:

NUE= (NU/NA) x 100

Where,

NUE = Nitrogen use efficiency (%)

NU = Total amount of nitrogen uptake (kg)

NA = Total amount of applied nitrogen (kg)

Soil moisture used by the crop throughout the growing period of the crop was determined by using the following formula:

$Sm = \{(M_S – M_H) / 100\} \times \rho b \times D \times A$

Where,

Sm = Soil moisture used by the crop (cm)

M_S = Soil moisture percentage at sowing (by weight basis)

M_H = Soil moisture percentage at harvest (by weight basis)

ρb = Bulk density (g cm^{-3})

D = Rooting depth (cm)

A = Area (m^2)

Data on rooting depth, total number of irrigation, common irrigation (transplanting to seedling establishment) and total amount of irrigation water are presented in Table 2.

Effective rainfall was determined by using the following equations:

$Pe = 0.8P – 25$ if $P > 75$ mm $month^{-1}$

$Pe = 0.6P – 10$ if $P < 75$ mm $month^{-1}$

Where,

Pe = Effective rainfall (mm)

P = Rainfall (mm)

The recorded data on different parameters were statistically analyzed by using the software, *R* 3.5.5 to find out the significance of variation resulting from the experimental treatments.

Table 1a. Physiography and observed soil physical characteristics of experimental sites

Parameters	Analytical value		Analytical method
	Gazipur	Lalmonirhat	
Agro-ecological zone (AEZ)	28 (Madhupur Tract)	03 (Tista Meander Floodplain)	
General soil type	Grey Terrace soil	Non-calcareous Grey Floodplain soil	
Soil Oder	Inceptisols	Inceptisols	
Soil Series	Chhiata series	Gangachara series	
Geographical Coordinate	$23^0 98^{/} 8^{//}$ North Latitude & $90^0 40^{/} 9^{//}$ East Longitude	$25^0 92^{/} 2^{//}$ North Latitude & $89^0 43^{/} 1^{//}$ East Longitude	
Particle size distribution			Hydrometer method
% Sand	31.5	35.7	
% Silt	30.1	39.2	
% Clay	38.4	25.1	
Textural class	Clay loam	Loam	
Bulk density (g cm^{-3})	1.38	1.41	Core sampling method
Particle density (g cm^{-3})	2.65	2.68	Pycnometer method
Porosity (%)	47.9	47.4	
Field capacity (% by weight)	31.9	29.5	Gravimetric method
Initial moisture content (% by weight)	24.8	23.6	Gravimetric method

Table 1b. Observed soil chemical properties of the experimental site

Soil Chemical Properties	Analytical value		Analytical method
	Gazipur	Lalmonirhat	
Soil pH	6.2	5.9	Soil: water=1:2.5
Organic carbon (%)	0.89	1.12	Wet oxidation method
Total N (%)	0.08	0.09	Micro Kjeldhal Method
Available P (ppm)	7.78	7.33	Bray and Kurtz method
Exchangeable K (meq 100 g^{-1} soil)	0.08	0.09	N NH_4OAc Extraction method
Available S (ppm)	6.57	6.34	Calcium dihydrogen phosphate extraction method
Available B (ppm)	0.18	0.21	Calcium chloride extraction method
Available Zn (ppm)	0.57	0.63	DTPA Extraction method
Available Cu (ppm)	0.17	0.19	DTPA Extraction method
Available Mn (ppm)	0.75	0.78	DTPA Extraction method
CEC (meq 100 g^{-1} soil)	9.3	9.9	N NH_4OAc Extraction method

Table 2. Amount of irrigation water applied in different soil moisture levels of onion

No. of irrigation	Rooting depth (cm)	Amount of irrigation water (mm) at different soil moisture regimes and nitrogen levels																	
		I_1N_1		I_1N_2		I_1N_3		I_2N_1		I_2N_2		I_2N_3		I_3N_1		I_3N_2		I_3N_3	
		Gaz	Lal	Gaz	Lal	Gaz	Lal	Gaz	Lal	Gaz	Lal	Gaz	Lal	Gaz	Lal	Gaz	Lal	Gaz	Lal
1st	5	7.03	6.4	8.5	8.01	6.5	7.1	10.1	7.1	9.6	10.3	9.7	10.7	15.7	13.5	16.2	18.5	29.4	27.7
2nd	5	10.03	8.5	12.5	9.01	10.2	7.8	10.7	10.8	10.5	10.7	14.4	15.3	16.3	15.9	25.5	22.1	33.5	30.5
3rd	5	12.07	11.1	15.9	9.2	13.7	11.7	19.7	16.7	17.7	16.1	22.1	19.1	17.5	20.5	28.7	25.7	30.1	35.1
4th	7	15.01	15.9	16.3	14.5	16.1	17.1	20.5	19.5	19.9	21.1	26.1	20.1	25.5	24.1	28.5	28.8	29.2	35.4
5th	7	18.02	18.2	15.7	15.7	16.7	17.4	22.2	21.1	24.7	23.7	27.4	22.2	29.8	234.7	32.4	28.7	-	-
6th	7	19.02	19.7	18.7	18.1	20.5	19.2	21.5	20.5	24.8	25.7	28.7	21.7	30.2	25.0	-	19.5	-	-
7th	10	21.01	21.5	23.8	23.1	24.7	19.2	25.9	23.6	24.7	26.1	20.1	23.7	-	18.4	-	-	-	-
8th	10	22.7	23.8	27.5	25.7	26.9	20.1	24.5	21.7	25.8	27.5	-	23.5	-	-	-	-	-	-
9th	10	25.4	20.2	28.0	26.7	28.9	20.4	-	17.0	-	-	-	-	-	-	-	-	-	-
10th	12	20.21	19.5	-	21.18	-	23.5	-	-	-	-	-	-	-	-	-	-	-	-
11th	12	-		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Common irrigation for plant establish		29	31	29	31	29	31	29	31	29	31	29	31	29	31	29	31	29	31
Total		199.5	204.2	195.9	202.2	193.2	194.5	184.1	189	186.7	192.2	177.5	187.3	164.0	173.1	160.3	174.3	151.2	159.7

Results and Discussion

Plant height

The individual as well as the interaction effects of irrigation regimes and nitrogen doses were significant for plant height of onion (Table 3-5). Considering the main effect of irrigation treatment the tallest plants (49.6 cm in Gazipur and 50.6 cm in Lalmonirhat) was recorded in irrigation at 10% depletion of field capacity (I_1). The application of N fertilizer significantly increased the plant height. The tallest plant (48.6 cm in Gazipur and 49.8 cm in Lalmonirhat) was recorded from the application of 150 kg N ha^{-1} (N_1) which was statistically similar with plants supplied with 100 kg N ha^{-1} (N_2). Due to interaction effects of irrigation regimes and nitrogen levels the highest plant height (52.4 cm in Gazipur and 53.3 cm in Lalmonirhat) was recorded from plot subjected to irrigation at 10% depletion of field capacity and application of 100 kg N ha^{-1} (I_1N_2). The lowest plant height (37.3 cm in Gazipur and 39.7 cm in Lalmonirhat) was recorded under irrigation at 30% depletion of field capacity and application of 50 kg N ha^{-1} (I_3N_3). The plant height might have increased due to the optimum availability of soil moisture and nitrogen, which enhanced cell division and elongation of the plant to attain maximum growth. Similar results were reported by Tolossa, 2021 and Tsegaye *et al*., 2016.

Number of leaves per plant

The number of leaves per plant was significantly influenced by individual as well as the combined effects of irrigation regimes and nitrogen doses for onion (Table 3-5). Taking into account as main effect of irrigation treatment, the maximum number of leaves per plant (14.2 in Gazipuar and 12.1 in Lalmonirhat) was recorded from irrigation at 10% depletion of field capacity (I_1). The application of N fertilizer also significantly increased the number of leaves per plant. The maximum number of leaves per plant (14.0 in Gazipur and 12.3 in Lalmonirhat) was noted from the application of 150 kg N ha^{-1} (N_1). When irrigation and nitrogen were applied in combination, the maximum number of leaves per plant (16.7 in Gazipur and 13.3 in Lalmonirhat) was found with irrigation at 10% depletion of field capacity and 150 kg N ha^{-1} (I_1N_1), while the minimum number of leaves per plant (9.7 in Gazipur and 9.3 in Lalmonirhat) was recorded in irrigation at 30% depletion of field capacity and 75 kg N ha^{-1} application. Water stress and nitrogen deficiency might have inhibited leaf expansion, reduced the amount of solar radiation, hampered cell turgor pressure, reduced CO_2 and nutrient uptake, photosynthesis and other biochemical processes, which ultimately affected the growth and development of onion. The transpiration and gas exchange also become limited due to stomatal closure, when crop grown under moisture and nutrient stress conditions. This result is in agreement with the findings of Tolossa, 2021 and Walle *et al*., 2018.

Neck thickness

The individual as well as the interaction effects of irrigation regimes and nitrogen doses on the neck thickness of onion were found significant (Table 3-5). In case of the main effect of irrigation treatment, the maximum neck thickness (0.95 cm in Gazipur and 0.87 cm in Lalmonirhat) was observed from irrigation at 10% depletion of field capacity (I_1). For the mean effect of N, the maximum neck thickness of onion (0.91cm in Gazipur and 0.84 cm in Lalmonirhat) was recorded under the application of 150 kg N ha^{-1} (N_1). The maximum mean neck thickness (1.12 cm in Gazipur and 1.0 cm in Lalmonirhat) was found from the plant grown with irrigation at 10% field capacity and application of 150 kg N ha^{-1}. Thick necked onions cannot be stored for the long time because these may have less capability of storing assimilates as well as vulnerable to rotting due to attack of pathogen. The results are in line with the findings of Nurga *et al*., 2020.

Days to maturity

The maturity sign of onion bulb commences by drying and fall of leaves at the neck which is called “neck fall”. If the goal is to store the onions in *kharif* season, rolling down onion tops encourages the onion to turn brown and stop taking up water, thus boosting the final process of ripening. Days to maturity referred to the number of days required from transplanting to 80% of the plant in a plot shows yellowing of leaves and neck fall. Results revealed that the individual as well as the interaction effects of irrigation regimes and nitrogen were significant for days to maturity of onion (Table 3-5). Considering the main effect as irrigation treatment, the maximum days required to mature onion bulb was (87.7 days in Gazipur and 90.1 days in Lalmonirhat) when irrigation applied at 10% depletion of field capacity (I_1). Application of N fertilizer significantly increased days to maturity. The maximum days required to mature of onion bulb (87.3 days in Gazipur and 87.4 days in Lalmonirhat) was observed by the application of 150 kg N ha^{-1}(N_1). Onion plants supplied with N 150 kg ha^{-1} and irrigation at 10% depletion of field capacity (I_1N_1) required maximum (92.3 in Gazipur and 95.3 in Lalmonirhat) days to mature while irrigation at 30% depletion of field capacity and 75 kg N ha^{-1} to onion plants required minimum (75.7 in Gazipur and 77.0 in Lalamonirhat) days to maturity. The results are in agreement with the findings of various researches who revealed that frequent and too much application of irrigation and nitrogen promoted excessive vegetative growth and delayed maturity (Nurga *et al*., 2020 and Tsegaye *et al*., 2016).

Table 3. Effect of irrigation regimes on vegetative growth parameters of onion

Treatment	Plant height (cm)		No. of leaves plant^{-1}		Neck thickness (cm)		Days to maturity	
	Gazipur	Lalmonirhat	Gazipur	Lalmonirhat	Gazipur	Lalmonirhat	Gazipur	Lalmonirhat
I_1	49.6a	50.6a	14.2a	12.1a	0.95a	0.87a	87.7a	90.1a
I_2	46.3b	49.7a	11.9b	10.7b	0.81b	0.74b	82.4b	82.8b
I_3	41.9c	43.3b	10.9c	10.0b	0.65c	0.66c	79.6c	79.1c
CV (%)	3.82	6.89	6.12	9.32	14.61	9.70	2.12	1.39

Table 4. Effect of nitrogen levels on vegetative growth parameters of onion

Treatment	Plant height (cm)		No. of leaves plant^{-1}		Neck thickness (cm)		Days to maturity	
	Gazipur	Lalmonirhat	Gazipur	Lalmonirhat	Gazipur	Lalmonirhat	Gazipur	Lalmonirhat
N_1	48.6a	49.8a	14.0a	12.3a	0.91a	0.84a	87.3a	87.4a
N_2	47.5a	49.8a	12.4b	11.8a	0.80a	0.77a	82.4b	84.4b
N_3	41.4b	44.0b	10.6c	9.7b	0.69b	0.66b	79.3c	80.1c
CV (%)	3.82	6.89	6.12	9.32	14.61	9.70	2.12	1.39

Table 5. Interaction effects of irrigation regimes and nitrogen levels on vegetative growth parameters of onion

Treatment	Plant height (cm)		No. of leaves $plant^{-1}$		Neck thickness (cm)		Days to maturity	
	Gazipur	Lalmonirhat	Gazipur	Lalmonirhat	Gazipur	Lalmonirhat	Gazipur	Lalmonirhat
I_1 X N_1	52.2a	53.0a	16.7a	13.3a	1.12a	1.0a	92.3a	95.3a
I_1 X N_2	52.4a	53.3a	14.7b	12.7ab	0.94ab	0.89ab	86.3b	91.3b
I_1 X N_3	44.1d	45.3cd	11.3de	10.3cd	0.79bcd	0.73cd	84.3b	83.7cd
I_2 X N_1	48.7b	51.7ab	13.3c	11.7abc	0.92ab	0.81bc	86.0b	85.3c
I_2 X N_2	47.7bc	50.3abc	11.7de	11.0bcd	0.82bc	0.74cd	83.3b	83.3cd
I_2 X N_3	42.7d	47.0bc	10.7ef	9.3d	0.67cd	0.66de	78.0cd	79.7ef
I_3 X N_1	44.7cd	44.7cd	12.0d	10.3cd	0.70cd	0.71cde	83.7b	81.7de
I_3 X N_2	43.7d	45.3cd	11.0de	10.3cd	0.65cd	0.68de	79.3c	78.7fg
I_3 X N_3	37.3e	39.7d	9.7f	9.3d	0.60d	0.59e	75.7d	77.0g
CV (%)	3.82	6.89	6.12	9.32	14.61	9.70	2.12	1.39

Legend: Irrigation levels: I_1=irrigation at 10%, I_2=20% and I_3=30% depletion of field capacity

Nitrogen levels: N_1=150 kg ha^{-1}, N_2=100 kg ha^{-1} and N_3=75 kg ha^{-1}

Bulb size

Onion bulb size refers to the length and diameter of the bulb. However, individual as well as the interaction effects of irrigation regimes and nitrogen doses showed significant variation for bulb size (Table 6-8). In case of the main effect of irrigation treatment, the biggest bulb (4.9 cm x 4.7 cm in Gazipur and 5.1cm x 4.8 cm in Lalmonirhat) was obtained from irrigation at 20% depletion of field capacity (I_1). The application of N fertilizer significantly increased the bulb size of onion. For that case, the biggest sized onion bulb (4.9 cm x 4.9 cm in Gazipur and 5.1 cm x 5.0 cm in Lalmonirhat) was obtained from the application of 100 kg N ha^{-1} (N_2). The maximum mean bulb length and diameter (5.1 cm x 5.2 cm in Gazipur and 5.5 cm x 5.2 cm in Lalmonirhat) was obtained from application of irrigation at 10% field capacity and N 100 kg ha^{-1}, whereas further increase had no significant effect. This result is in agreement with Nurga *et al.* (2020) and Tsegaye *et al.* (2016), who reported that optimum combinations of N and irrigation enhance the formation of bulb.

Single bulb weight

The single bulb weight of onion was significantly influenced by individual and interaction effect of irrigation regimes and nitrogen levels (Table 6-8). For the main effect of irrigation, the maximum single bulb weight (51.6 g in Gazipur and 52.9 g in Lalmonirhat) was obtained from irrigation at 20% depletion of field capacity (I_2), which was statistically similar to irrigation at 10% depletion of field capacity (I_1). The application of N fertilizer significantly increased the single bulb weight of onion. The maximum single bulb weight (51.3 g in Gazipur and 53.8 g in Lalmonirhat) was recorded due to the application of 100 kg N ha^{-1} (N_2). Optimum combination of irrigation regimes and nitrogen levels increased single bulb weight but deficit irrigation and over dose of N caused reduction in single bulb weight. However, for interaction effect, the treatment I_1N_2 (irrigation at 10% depletion of field capacity and application of 100 kg N ha^{-1}) gave the highest single bulb weight (55.1 g in Gazipur and 56.7 g in Lalmonirhat). Soil moisture and nitrogen help to translocate photosynthates form leaves to bulbs which might have resulted in single bulb weight. Similar kind of result was reported by Fatideh and Asil, 2012.

Total soluble solids (TSS)

Effect of irrigation regimes and nitrogen doses and their interactions were found to be non-significant for total soluble solid (TSS ^{0}Brix) content in onion (Table 6-8). Highest TSS values (12.99^{0}Brix in Gazipur and 13.3^{0}Brix in Lalmonirhat) were noted by applying irrigation at 10% depletion of field capacity (I_1) followed by I_2 and the lowest (12.60 ^{0}Brix in Gazipur and 13.1 ^{0}Brix in Lalmonirhat) from that of irrigation at 30 % depletion of field capacity (I_3). For main effect of N, the maximum TSS of onion (12.70^{0}Brix and 13.3^{0}Brixin Gazipur and Lalmonirhat

Location, respectively) was observed by the application of 150 kg N ha^{-1} (N_1). For the interaction effect, the maximum mean TSS (12.83^{0}Brix in Gazipur and 13.4^{0}Brix in Lalmonirhat) of onion was obtained from irrigation at 10% field capacity with application of 150 kg N ha^{-1}. These findings revealed that TSS is more likely influenced by the environmental factors. The results are in agreement with the findings of Walle *et al*., 2018.

Total bulb yield

Total bulb yield of onion was significantly influenced by the individual as well as the interaction effects of irrigation regimes and nitrogen levels (Table 9-11). Considering the main effect of irrigation, the maximum bulb yield (19.84 t ha^{-1} in Gazipur and 21.17 t ha^{-1} in Lalmonirhat) was obtained from irrigation at 10% depletion of field capacity (I_1). However, the maximum bulb yield of onion (19.9 t ha^{-1} in Gazipur and 21.13 t ha^{-1} in Lalmonirhat) was observed from the application of 100 kg N ha^{-1} (N_2). The combined effect of irrigation at 10% depletion of field capacity and application of 100 kg N ha^{-1} gave the highest total bulb yield of onion (21.49 t ha^{-1} in Gazipur and 22.79 t ha^{-1} in Lalmonirhat). The lowest total bulb yield (14.46 t ha^{-1} in Gazipur and 16.02 t ha^{-1} in Lalmonirhat) was recorded from irrigation at 30% depletion of field capacity and application of 75 kg N ha^{-1}. Optimum irrigation and nitrogen levels might have increased the rate of metabolism which resulted in more synthesis of carbohydrate, translocation of metabolites and proper functioning of phytohormones and ultimately increased total bulb yield of onion. These results are in close conformity with Tsegaye *et al.*, 2016 and Fatideh and Asil, 2012.

Marketable bulb yield

The individual effect as well as the interaction effects of irrigation regimes and nitrogen levels on the marketable bulb yield of onion were significant (Table 9-11). For the main effect of irrigation, the highest marketable bulb yield of onion (16.6 t ha^{-1} in Gazipur and 18.4 t ha^{-1} in Lalmonirhat) were recorded from irrigation at 10% depletion of field capacity, whereas the minimum from (12.1 t ha^{-1} in Gazipur and 14.9 t ha^{-1} in Lalmonirhat) from irrigation at 30% depletion field capacity. Considering the main effect of nitrogen levels, the maximum marketable bulb yield (16.1 t ha^{-1} in Gazipur and 18.6 t ha^{-1} in Lalmonirhat) was obtained from 100 kg N ha^{-1} and the minimum (13.8 t ha^{-1} in Gazipur and 15.7 t ha^{-1} in Lalmonirhat) from 50 kg N ha^{-1}. However, for the interaction effect, treatment I_1N_2 (irrigated at 10% depletion of field capacity and application of 100 kg N ha^{-1}) gave the highest marketable bulb yield (18.0 t ha^{-1} in Gazipur and 20.0 t ha^{-1} in Lalmonirhat) and the minimum value (10.6 t ha^{-1} in Gazipur and 13.6 t ha^{-1} in Lalmonirhat) were obtained in treatment I_3N_3 (irrigation at 30% depletion of field capacity and application of 50 kg N ha^{-1}). Similar results are depicted by Nurga *et al.* (2020), Fatideh and Asil (2012) and Nasreen *et al.* (2007).

Table 6. Effect of irrigation regimes on yield parameters and TSS of onion

Treatment	Bulb length (cm)		Bulb diameter (cm)		Single bulb weight (g)		TSS(^{0}Brix)	
	Gazipur	Lalmonirhat	Gazipur	Lalmonirhat	Gazipur	Lalmonirhat	Gazipur	Lalmonirhat
I_1	4.7a	4.7b	4.6a	4.7a	50.8a	52.0a	12.99	13.3
I_2	4.9a	5.1a	4.7a	4.8a	51.6a	52.9a	12.64	13.2
I_3	3.8b	4.4c	3.9b	4.4b	41.0b	46.6b	12.60	13.1
CV (%)	9.84	4.15	6.82	3.80	4.69	3.67	NS	NS

Table 7. Effect of nitrogen levels on yield parameters and TSS of onion

Treatment	Bulb length (cm)		Bulb diameter (cm)		Single bulb weight (g)		TSS(^{0}Brix)	
	Gazipur	Lalmonirhat	Gazipur	Lalmonirhat	Gazipur	Lalmonirhat	Gazipur	Lalmonirhat
N_1	4.6a	4.7b	4.3b	4.5b	49.0b	50.4b	12.70	13.3
N_2	4.9a	5.1a	4.9a	5.0a	51.3a	53.8a	12.59	13.2
N_3	3.9b	4.4c	3.9c	4.4b	43.0c	47.2b	12.64	13.3
CV (%)	9.84	4.15	6.82	3.80	4.69	3.67	NS	NS

Table 8. Interaction effect of irrigation regimes and nitrogen levels on yield parameters and TSS of onion

Treatment	Bulb length (cm)		Bulb Diameter (cm)		Single bulb weight (g)		TSS(^{0}Brix)	
	Gazipur	Lalmonirhat	Gazipur	Lalmonirhat	Gazipur	Lalmonirhat	Gazipur	Lalmonirhat
I_1 X N_1	5.1a	5.1b	4.4b	4.6b	55.0a	55.0ab	12.83	13.4
I_1 X N_2	5.1a	5.5a	5.2a	5.2a	55.1a	56.7a	12.70	13.4
I_1X N_3	4.4abc	4.6cd	4.4b	4.5bc	45.0cd	49.3de	12.60	13.1
I_2 X N_1	4.7ab	4.7bc	4.4b	4.7b	51.7ab	52.0bcd	12.63	13.2
I_2 X N_2	5.1a	5.1b	5.1a	5.1a	52.0a	52.7bc	12.67	13.3
I_2 X N_3	4.3bc	4.4de	4.2b	4.4bcd	48.0bc	49.0de	12.50	13.1
I_3 X N_1	3.9c	4.4cde	4.1b	4.3cd	43.3d	46.7e	12.63	13.2
I_3 X N_2	4.4abc	4.7bc	4.3b	4.7b	43.7d	49.7de	12.67	13.3
I_3 X N_3	3.0d	4.1e	3.2c	4.2d	36.0e	43.3f	12.57	13.1
CV (%)	9.48	4.15	6.82	3.80	4.69	3.67	NS	NS

Legend: Irrigation levels: I_1=irrigation at 10%, I_2=20% and I_3=30% depletion of field capacity

Nitrogen levels: N_1=150 kg ha^{-1}, N_2=100 kg ha^{-1} and N_3=75 kg ha^{-1}

Biomass yield

The single as well as the interaction effect of irrigation regimes and nitrogen levels were significant variation for biomass yield (Table 9-11). For the main effect of irrigation, the maximum biomass yield (2.82 t ha^{-1} in Gazipur and 3.40 t ha^{-1} in Lalmonirhat) were obtained from irrigation at 10% depletion of field capacity (I_1). Considering the main effect of nitrogen, the maximum biomass yield (2.78 t ha^{-1} and 3.22 t ha^{-1} in Gazipur and Lalmonirhat Location, respectively) was recorded from the application of 100 kg N ha^{-1} (N_2). The highest biomass yield of onion (3.01 t ha^{-1} in Gazipur and 3.29 t ha^{-1} in Lalmonirhat) was recorded in treatment I_1N_2. Water and nitrogen availability in the root zone, leads to enhance plant growth and development (Tolossa, 2021; Bangali, 2012 and Kumar *et al*., 2007).

Harvest Index

The individual as well as interaction effects of irrigation regimes and nitrogen levels on harvest index of onion are presented in Table 9-11. Considering the main effect of irrigation, the maximum (588.65% in Gazipur and 599.35% in Lalmonirhat) from irrigation at 10% depletion of field capacity and the minimum value (555.05% in Gazipur and 568.70% in Lalmonirhat) was obtained from irrigation at 30% depletion of field capacity. For the main effect of nitrogen, the maximum harvest index (579.14% in Gazipur and 741.0% in Lalmonirhat) from 100 kg N ha^{-1} and minimum value (558.7% in Gazipur and 644.19% in Lalmonirhat) was recorded from 50 kg N ha^{-1}. The interaction effect of irrigation at 10% depletion of field capacity along with 100kg Nha^{-1} gave the maximum harvest index (598.0% in Gazipur and 607.9% in Lalmonirhat) and the minimum (517.07% and 541.83% in Gazipur and Lalmonirhat location, respectively) were noted in I_3N_3.

Nitrogen content

Nitrogen content per plant was significantly influenced by individual and interaction effects of irrigation regimes and nitrogen levels. (Table 12-14). Considering the main effect of irrigation, the maximum N content per plant (2.62% in Gazipur and 2.69% in Lalmonirhat) was recorded from irrigation at 10% depletion of field capacity (I_1), being significantly higher over rest of the irrigation level. Application of nitrogen fertilizer significantly increased the nitrogen content in onion plant. The maximum N content per plant (2.56% in Gazipur and 2.66% in Lalmonirhat) was noted with the application of 150 kg N ha^{-1} (N_1). It was observed that irrigation at 10% depletion of field capacity and application of 100 kg N ha^{-1} contributed to the maximum nitrogen content in plant (2.76% in Gazipur and 2.87% in Lalmonirhat), which was statistically similar to I_1N_2 (2.71% in Gazipur and 2.78% in Lalmonirhat). The minimum N content (1.99% in Gazipur and 2.05% in Lalmonirhat) was noted in I_3N_3 (irrigation at 30% depletion of field capacity and application of 75kg Nha^{-1}).

Table 9. Effect of irrigation regimes on bulb yield, biomass yield and harvest index of onion

Treatment	Total bulb yield(tha^{-1})		Marketable yield (tha^{-1})		Biomass yield (tha^{-1})		Harvest index (%)	
	Gazipur	Lalmonirhat	Gazipur	Lalmonirhat	Gazipur	Lalmonirhat	Gazipur	Lalmonirhat
I_1	19.84a	21.17a	16.6a	18.4a	2.82a	3.40a	588.65	599.35
I_2	18.68b	19.85b	16.1a	17.6a	2.81b	2.93b	572.95	588.63
I_3	15.99c	17.18c	12.1b	14.9b	2.18c	2.38c	555.05	568.70
CV (%)	6.09	7.84	5.93	7.31	7.22	11.25	-	-

Table 10. Effect of nitrogen levels on bulb yield, biomass yield and harvest index of onion

Treatment	Total bulb yield(tha^{-1})		Marketable yield (tha^{-1})		Biomass yield (tha^{-1})		Harvest index (%)	
	Gazipur	Lalmonirhat	Gazipur	Lalmonirhat	Gazipur	Lalmonirhat	Gazipur	Lalmonirhat
N_1	18.56b	19.48b	14.9b	16.62b	2.58b	2.98a	577.52	644.19
N_2	19.90a	21.13a	16.1a	18.6a	2.78a	3.22a	579.14	741.04
N_3	16.06c	17.60c	13.8c	15.7b	2.47c	2.51b	558.7	716.89
CV (%)	6.09	7.84	5.93	7.31	7.22	11.25	-	-

Table 11. Interaction effect of irrigation regimes and nitrogen levels on bulb yield, biomass yield and harvest index of onion

Treatment	Total bulb yield(tha^{-1})		Marketable yield (tha^{-1})		Biomass yield (tha^{-1})		Harvest index (%)	
	Gazipur	Lalmonirhat	Gazipur	Lalmonirhat	Gazipur	Lalmonirhat	Gazipur	Lalmonirhat
I_1 X N_1	20.61ab	21.66b	16.3bc	18.1abc	2.79c	3.03b	584.23	597.36
I_1 X N_2	21.49a	22.79a	18.0a	20.0a	3.01a	3.29a	598.0	607.9
I_1X N_3	17.41d	19.07d	15.4c	17.2bc	2.67f	2.89c	576.78	595.16
I_2 X N_1	19.23c	20.14c	15.9bc	17.0c	2.77d	2.91c	574.01	584.19
I_2 X N_2	20.52b	21.73b	17.1ab	19.3ab	3.0a	3.27a	570.0	590.21
I_2 X N_3	16.30e	17.70e	15.4c	16.4cd	2.68e	2.81d	574.63	583.63
I_3 X N_1	15.84e	16.63f	12.4d	14.7de	2.18h	2.59e	568.81	567.57
I_3 X N_2	17.69d	18.88d	13.2d	16.4cd	2.32g	2.76d	568.97	594.20
I_3 X N_3	14.46f	16.02f	10.6e	13.6e	2.05i	2.51f	517.07	541.83
CV (%)	6.09	7.84	5.93	7.31	7.22	11.25	-	-

Legend: Irrigation levels: I_1=irrigation at 10%, I_2=20% and I_3=30% depletion of field capacity

Nitrogen levels: N_1=150 kg ha^{-1}, N_2=100 kg ha^{-1} and N_3=75 kg ha^{-1}

Nitrogen uptake

Nitrogen uptake by onion plant was varied due to single and as well as combined application of irrigation and nitrogen (Table-12-14). Considering the sole effect of irrigation, the maximum nitrogen uptake (73.88 kg ha^{-1} in Gazipur and 82.58 kg ha^{-1} in Lalmonirhat) was observed with irrigation at 10% depletion of field capacity (I_1) and the minimum value (48.4 kg ha^{-1} in Gazipur and 61.05 kg ha^{-1} in Lalmonirhat) was found from irrigation at 30% depletion of field capacity (I_3). Application of nitrogen fertilizer also influenced the uptake of nitrogen. The maximum nitrogen uptake (69.78kg ha^{-1} in Gazipur and 65.51 kg ha^{-1} in Lalmonirhat) were observed from 100 kg N ha^{-1} (N_2) and the minimum (47.18 kg ha^{-1} in Gazipur and 49.93 kg ha^{-1} in Lalmonirhat) were observed from the lowest dose of 75 kg N ha^{-1}. The interaction effect of irrigation and nitrogen levels on N uptake of onion was also varied appreciably. The highest nitrogen uptake (81.57kg ha^{-1} in Gazipur and 91.46kg ha^{-1} in Lalmonirhat) was observed in I_1N_2 (irrigation at 10% depletion of field capacity and application of 100 kg Nha^{-1}). This corresponds to early findings of El-Hadidi *et al*. (2016) and Nasreen *et al.* (2007).

Nitrogen use efficiency

Nitrogen use efficiency of onion varied due to irrigation regimes and nitrogen levels (Table-12-14). Among the main effect of irrigation treatments, the maximum of nitrogen use efficiency (46.96% in Gazipur and 52.49% in Lalmonirhat) was recorded with irrigation at 10% depletion of field capacity (I_1) and the minimum (30.76% in Gazipur and 38.80% in Lalmonirhat) at 30% depletion of field capacity (I_3). On the other hand, the maximum nitrogen use efficiency (46.83% in Gazipur and 43.97% in Lalmonirhat) was observed by the application of 100 kg N ha^{-1} (N_2). The interaction effect of irrigation and N levels on N use efficiency of onion was considerable. The highest nitrogen use efficiency (54.74% in Gazipur and 61.38% in Lalmonirhat) was obtained from irrigation at 10% depletion of field capacity along with application of 100 kg Nha^{-1}(I_1N_2). Similar results on nitrogen use efficiency of onion were reported by Kumara *et al.* (2018) and Nasreen *et al.* (2007).

Table 12. Effect of irrigation regimes on nitrogen use efficiency of onion

Treatment	N content per plant (%)		N uptake ($kgha^{-1}$)		N use efficiency (%)	
	Gazipur	Lalmonirhat	Gazipur	Lalmonirhat	Gazipur	Lalmonirhat
I_1	2.62a	2.69a	73.88	82.58	46.96	52.49
I_2	2.44b	2.54b	68.56	75.95	43.58	48.27
I_3	2.22c	2.33c	48.40	61.05	30.76	38.80
CV (%)	2.46	4.78	-	-	-	-

Table 13. Effect of nitrogen levels on nitrogen use efficiency of onion

Treatment	N content per plant (%)		N uptake (kgha^{-1})		N use efficiency (%)	
	Gazipur	Lalmonirhat	Gazipur	Lalmonirhat	Gazipur	Lalmonirhat
N_1	2.58a	2.66a	66.56	68.63	33.45	34.49
N_2	2.51b	2.61a	69.78	65.51	46.83	43.97
N_3	1.91c	2.28b	47.18	49.93	38.05	40.27
CV (%)	2.46	4.78	-	-	-	-

Table 14. Interaction effect of irrigation regimes and nitrogen levels on nitrogen use efficiency of onion

Treatment	N content per plant (%)		N uptake (kgha^{-1})		N use efficiency (%)	
	Gazipur	Lalmonirhat	Gazipur	Lalmonirhat	Gazipur	Lalmonirhat
I_1 X N_1	2.76a	2.87a	77.0	86.96	38.69	43.69
I_1 X N_2	2.71ab	2.78ab	81.57	91.46	54.74	61.38
I_1X N_3	2.39d	2.41d	63.81	69.65	51.46	56.17
I_2 X N_1	2.61bc	2.63bc	72.30	76.53	36.33	38.46
I_2 X N_2	2.53c	2.62bc	75.90	85.67	50.94	57.49
I_2 X N_3	2.19e	2.38d	58.69	66.88	47.33	53.94
I_3 X N_1	2.38d	2.50cd	51.88	64.75	26.07	32.54
I_3 X N_2	2.29d	2.44cd	53.13	67.34	35.66	45.19
I_3 X N_3	1.99f	2.05e	40.80	51.46	32.90	41.50
CV (%)	2.46	4.78	-	-	-	-

Legend: Irrigation levels: I_1=irrigation at 10%, I_2=20% and I_3=30% depletion of field capacity

Nitrogen levels: N_1=150 kg ha^{-1}, N_2=100 kg ha^{-1} and N_3=75 kg ha^{-1}

Storability

Onion is a non-climacteric perishable crops producing low endogenous ethylene during storage and encounters 35-40% post-harvest losses during storage owing to decay, sprouting and physiological weight loss (Anbukkarasi *et al.*, 2013). The storability of onion depends on variety, bulb size, shape with content of TSS, maturity at harvest, production technologies, storage condition and climatic condition. The physiological loss of weight (PLW) of onion was increased both with water deficit and nitrogen deficiency conditions up to 120 days of storage (Fig. 1 & 2). Total PLW was higher (16.3% in Gazipur and 21.1% in Lalmonirhat) for I_1N_1 (irrigation at 10% depletion of field capacity and application of 150 kg N ha^{-1}) during 120 days of storage. On the other hand, the minimum storage loss (11.8% in Gazipur and 15% in Lalmonirhat) was recorded from I_2N_2 (irrigation at

20% depletion of field capacity and application of 100 kg Nha^{-1}) during 120 days of storage. Onion grown under higher soil moisture regimes and higher nitrogen levels usually produced bigger bulb and tends to loss more weight and increase susceptibility to diseases and early sprouting during storage. On the other hands, onion grown under lower soil moisture and lower nitrogen level produced smaller sized bulb and less physiological weight loss to keep well during the 120 days storage period than onion grown under optimum soil moisture (Irrigation at 20% depletion of field capacity) and nitrogen levels (100 kg N ha^{-1}). Irrigation should be stopped before 15-20 days before attaining maturity to improve the keeping quality of bulbs. Similar results were reported by Kumar *et al.* (2007); Fatideh and Asil (2012).

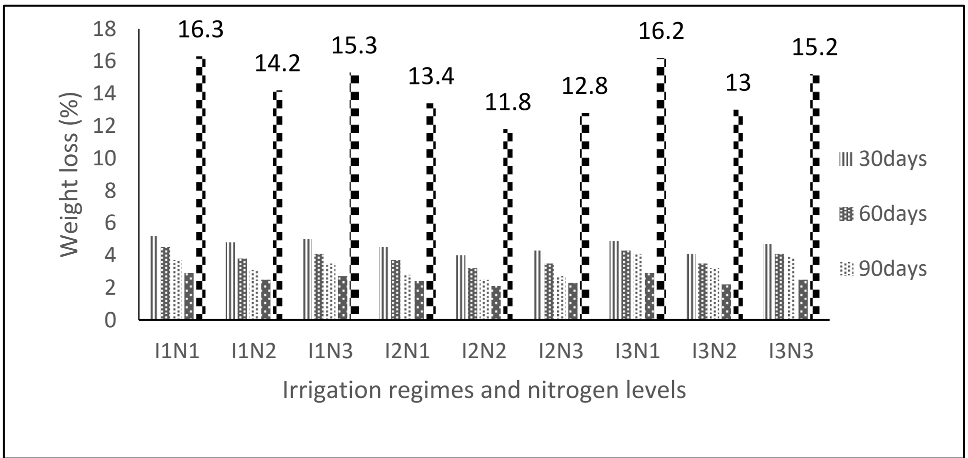

Fig. 1. Effect of irrigation and nitrogen levels on storability of onion at Gazipur.

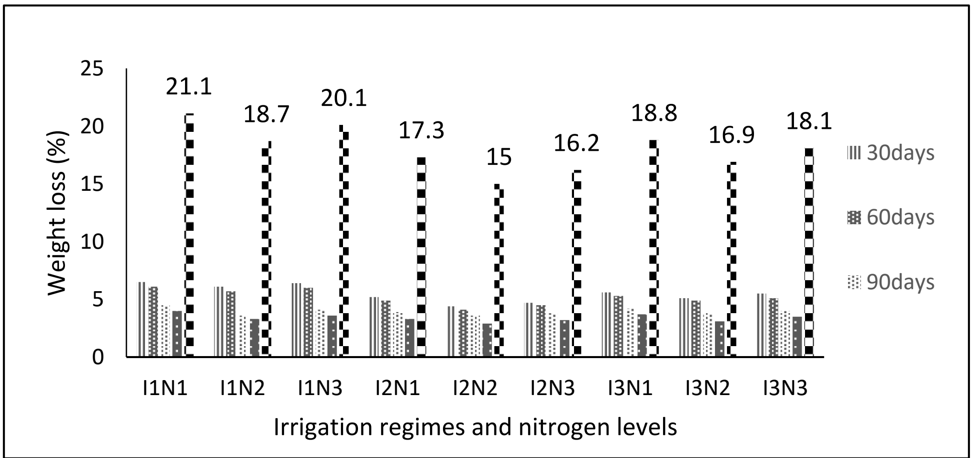

Fig. 2. Effect of irrigation and nitrogen levels on storability of onion at Lalmonirhat.

Table 15a. Total amount of irrigation water, soil moisture contribution and effective rainfall of onion affected by irrigation regimes and nitrogen levels

Treatment	Common irrigation (mm)		No. of irrigation		Amount of imposed irrigation water (mm)		Total amount of irrigation (mm)		Soil moisture contribution (mm)		Effective rainfall (mm)	
	A		-		B		C= A+B		D		E	
	Gazi	Lalmoni	Gazi	Lalmoni	Gazi	Lalmoni	Gazi	Lalmoni	Gazi	Lalmoni	Gazi	Lalmoni
I_1 X N_1	29.0	31.0	10	11	170.5	173.2	199.5	204.2	6.8	7.9	0	0
I_1 X N_2	29.0	31.0	9	10	166.9	171.2	195.9	202.2	7.3	8.7	0	0
I_1X N_3	29.0	31.0	9	10	164.2	163.5	193.2	194.5	8.7	10.5	0	0
I_2 X N_1	29.0	31.0	8	9	155.1	158.0	184.1	189.0	10.2	12.5	0	0
I_2 X N_2	29.0	31.0	8	8	157.7	161.2	186.7	192.2	12.9	12.6	0	0
I_2 X N_3	29.0	31.0	7	8	148.5	156.3	177.5	187.3	13.2	13.7	0	0
I_3 X N_1	29.0	31.0	6	7	135.0	142.1	164.0	173.1	13.7	13.7	0	0
I_3 X N_2	29.0	31.0	5	6	131.3	143.3	160.3	174.3	14.9	14.5	0	0
I_3 X N_3	29.0	31.0	4	4	122.2	128.7	151.2	159.7	15.2	14.9	0	0

Table 15b. Total consumptive use of irrigation water, water use efficiency of onion affected by irrigation regimes and nitrogen levels

Treatment	Total consumptive use of water (mm)		Water use efficiency (kg $ha^{-1}mm^{-1}$)	
	F = C + D + E		Total bulb yield / F	
	Gazipur	Lalamonirhat	Gazipur	Lalamonirhat
I_1 X N_1	206.3	212.1	99.90	102.12
I_1 X N_2	203.2	210.9	105.76	108.06
I_1X N_3	201.9	205.0	86.23	93.68
I_2 X N_1	194.3	201.5	98.97	99.95
I_2 X N_2	199.6	204.8	102.81	106.1
I_2 X N_3	190.7	201.0	85.47	88.06
I_3 X N_1	177.8	186.8	89.09	89.03
I_3 X N_2	175.2	188.8	100.97	100.0
I_3 X N_3	166.4	174.6	86.89	91.75

Legend: Irrigation levels: I_1=irrigation at 10%, I_2=20% and I_3=30% depletion of field capacity

Nitrogen levels: N_1=150 kg ha^{-1}, N_2=100 kg ha^{-1} and N_3=75 kg ha^{-1}

Consumptive use of water and water use efficiency

Irrigation water is the most crucial factor for onion cultivation. Bulb yield reduction should be compensated by maximizing water use efficiency. The effect of irrigation regimes and N levels on soil moisture contribution, total consumptive use of water and water use efficiency of onion was shown in Table 15a and Table 15b. The soil moisture contribution was the maximum in treatment I_3N_3 (15.2 mm in Gazipur and 14.9 mm in Lalmonirhat) and the minimum in I_1N_1 (6.8 mm in Gazipur and 7.9 mm in Lalmonirhat). The maximum consumptive use of water was noted in treatment I_1N_1 (206.3 mm in Gazipur and 212.1mm in Lalmonirhat). The minimum value was mentioned in treatment I_3N_3 (166.4 mm in Gazipur and 174.6 mm in Lalmonirhat). The maximum water use efficiency (105.76 kg ha^{-1} mm^{-1} in Gazipur and 108.06 kg ha^{-1} mm^{-1} in Lalmonirhat) was found in treatment I_1N_2 in both the locations. The results of these studies were in harmony to the findings of Tsegaye *et al*., 2016.

Conclusion

Onion was found responsive to both irrigation regimes and nitrogen doses. Both deficient water and nitrogen deficiency reduce bulb yield, biological yield, days to maturity, nitrogen uptake, nitrogen use efficiency, water productivity and storability of onion. Application of irrigation at 10% depletion of soil moisture over field capacity and 100 kg N ha^{-1} may be suitable for onion cultivation in the soils under AEZ-3 (Tista Meander Floodplain) and AEZ-28 (Madhupur Tract) in Bangladesh.

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