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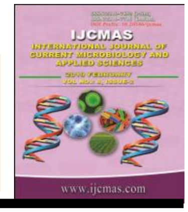

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Effect of Irrigation and Nitrogen Levels on Nutrient Uptake, Water Use Efficiency and Productivity of Onion (*Allium cepa* L.) in Himachal Pradesh

Samir Bhatti*, J.C. Sharma and Ridham Kakar

Department of Soil Science and Water Management,
Dr YS Parmar University of Horticulture and Forestry, Nauni-Solan (HP) 173230, India

**Corresponding author*

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A B S T R A C T

Field experiments were conducted during 2015-16 and 2016-17 to study the effect of irrigation and N levels on nutrient uptake, water use efficiency and productivity of onion (*Allium cepa* L.) in Himachal Pradesh. Twelve treatment combinations comprising four irrigation level i.e. 4 cm irrigation at IW/CPE ratio 1.2 (I_1), 1.0 (I_2), 0.8 (I_3), 0.6 (I_4) and three N levels i.e. 75 (N_1), 100 (N_2) and 125 per cent (N_3) of recommended dose of N, were replicated thrice in a Randomized Block Design. Nutrient uptake and bulb yield were at par under I_1 and I_2 levels and both these levels exhibited higher WUE, (115.1 and 104.9 kg ha^{-1}mm^{-1}) was recorded under I_1 followed by I_2 (109.7 and 104.6 kg ha^{1}mm^{-1}) with (35.42 and 39.14 cm) and (34.45 and 37.29 cm) of total water requirement during both the years of study, hence I_2 was considered as efficient irrigation level. Among N levels, N_3 was found to be optimum as it recorded significantly higher productivity of onion crop over N_2 and N_1 levels. Pooled analysis of the data showed that the combinations of I_1N_3 and I_2N_3 gave significantly higher bulb yield (467.0 q ha^{-1} and 435.5 q ha^{-1}) and were noted to be 53.7 and 43.3 per cent higher over I_4N_1. The study led to a conclusion that the combination of irrigation level I_2 (4 cm irrigation at 1.0 IW/CPE) with N_3 level (125% of RD of N) (I_2N_3) could be the best for maximising yield of onion with efficient use of scarce irrigation water in Himachal Pradesh.

Introduction

Onion is an important crop of Himachal Pradesh, but the productivity of the crop is quite low owing to lack of assured availability of irrigation water, sub optimal and imbalanced use of fertilizer nutrients, improper management of soil and water resources and inadequate crop management practices, weed control and plant protection measures, etc. Among various factors involved, nutrient and moisture supply are important inputs for realizing higher onion yield. Irrigation scheduling is a critical management input to ensure optimum soil moisture regime for proper growth and development as well as for optimum yield and economic benefits. Well managed irrigation can lead to increased yields, greater farmer profit, and significant water savings, reduced environmental impacts and improved sustainability of irrigated agriculture (Evett *et al.,* 2011; Gill *et al.,* 2011). It has been documented that effect of irrigation and nitrogen is negligible if proper irrigation schedule is not followed. Irrigation scheduling and nitrogen levels in accordance with crop sensitivity to irrigation and nutrients during the growing cycle can hide the effects of other growth and yield affecting factors, such as rainfall amount and distribution pattern. Present study, therefore, was undertaken to determine optimum irrigation schedule and nitrogen level to achieve higher productivity of onion in Himachal Pradesh.

Materials and Methods

Field experiments were conducted during two crop years (2015-2016) at the experimental farm of Department of Soil Science and WM, Dr YS Parmar University of Horticulture and Forestry, Solan (HP). The soil (Typic Eutrochrept) was gravelly loam in texture. Salient physical and chemical properties of the experimental soil of 0-15 cm depth were pH 6.91, organic carbon (%) 0.93, available N, P and K 245.30, 33.16 and 260.20 kg ha^{-1}, respectively. Moisture retention at FC and PWP were 24.05 and 7.5 per cent in 0-15 cm depth, respectively. The experiment was laid out with 12 treatments replicated thrice in randomized block design. Recommended dose (100%) of FYM, N, $P_2 O_5$ and K_2O is 25 t ha^{-1}, 125, 75 and 60 kg ha^{-1}, respectively, and were applied as per the treatments of the experiment in the form of Urea, single super-phosphate and murate of potash. Entire dose of FYM, P and K fertilizers was applied at the time of field preparation. The N fertilizer was applied in two split doses, first dose at the time of transplanting and second dose one month after transplanting and third dose two months after transplanting. Soil moisture contents in 0-7.5 and 7.5-15 cm depths were determined before and 24 hours after each irrigation to know the moisture regimes under different irrigation levels and the data has been presented for both the years of study. Leaf samples were collected and processed according to the method suggested by Chapman (1964). The nutrient contents were determined following standard methods for the analysis. The uptake of nutrients was calculated from data on contents (%) of the given nutrient in root, leaf and bulb multiplied by the corresponding dry matter yield. The data of each parameter for two crop seasons (2015-16 and 2016-17) have been presented.

Results and Discussion

Soil moisture contents before and after irrigation

Maximum soil moisture contents was noticed under I_1 (4 cm irrigation at 1.2 IW/CPE ratio) irrigation level which ranged from 22.46-27.24 and 22.78-28.45 per cent with mean values of 25.94 and 26.27 per cent, which was slightly higher than the field capacity during both the years (Table 1). Minimum soil moisture contents were recorded in I_4 (4 cm irrigation at IW/CPE ratio 0.6) irrigation level which ranged from 17.79-21.88 and 18.79-22.97 per cent with mean values of 19.72 and 20.88 per cent, which was 18.0 and 13.5 per cent lower than the field capacity during the year 2016 and 2017, respectively. In 7.5-15 cm depth after irrigation mean values varied from 17.60-22.80 and 18.10-23.60 per cent during the year 2016 and 2017, respectively. Maximum soil moisture contents were noticed under I_1 irrigation level which ranged from 18.14-24.32 and 19.74-25.12 per cent with mean values of 22.80 and 23.60 per cent, which were near to field capacity during both the years of study. Minimum soil moisture contents were recorded in I_4 (4 cm irrigation at

IW/CPE ratio 0.6) irrigation level which ranged from 15.78-19.12 and 16.48-19.72 per cent with mean values of 17.60 and 18.10 per cent, which were 26.8 and 24.7 per cent lower than the field capacity during the year 2016 and 2017, respectively. Higher soil moisture contents under I_1 and I_2 irrigation level were due to frequent irrigations, whereas, comparatively lower moisture contents under I_3 and I_4 treatment were due to longer interval between successive irrigations. Higher moisture contents due to higher frequency of irrigations did not show any visual stress on various physiological processes, resulting in better uptake of nutrients and finally increased plant growth; yields attributes and yield (Kuchenbuch *et al.*, 2006; Patel *et al.*, 2008; Kumari, 2013).

Available NPK in soil

Irrigation as well as N levels and their interaction exhibited significant effect on available N, P and K in 0-15 cm soil depth (Table 2-4). Maximum contents of available N (365.5 and 357.6 kg ha^{-1}), P (57.23 and 53.29 kg ha^{-1}) and K (377.1 and 376.6 kg ha^{-1}) were recorded under I_1 followed by I_2 and these were significantly higher over I_3 and I_4 during both the years of study. Among N levels, N_3 recorded higher available N, P and K, i.e. (385.9 and 358.4 kg ha^{-1}), (53.74 and 49.34 kg ha^{-1}), and (374.5 and 367.6 kg ha^{-1}) which were at par with N_2 and significantly higher over N_1. Interactions between irrigation and N levels were also significant and maximum contents of N (400 and 402.7 kg ha^{-1}), P (63.67 and 59.93 kg ha^{-1}) and K (410.7 and 396.9 kg ha^{-1}) were recorded under I_1N_3 which were at par with I_2N_3 and significantly higher over other treatment combinations. Higher availability of N with increasing levels of N is quite obvious and might be due to favourable soil moisture regimes and the positive effect of irrigation schedules and N levels. Nitrogen, as nitrate and ammonium is highly soluble and moves rapidly in soil and thus available N increased with favourable soil moisture contents. The significant build-up of the available N due to N application could also be attributed to increased activity of nitrogen fixing bacteria thereby resulting in higher accumulation of nitrogen in soil (Kumar, 2002). Increase in available P contents with increasing levels of N might be due to lower utilization of applied P by the crop resulting in build up of soil P status. Another possible reason for increase in P contents may be partly attributed to the activity of certain P solubilising microbes which are more in soils having high OC contents and adequate soil moisture thus releasing organic acids which are responsible for conversion of unavailable P to available form as well as the mineralization of soil organic matter/FYM by the microbes which also contribute to the pool of P (Lapeyne *et al.*, 1991). The enhanced status of soil K could be due to high native K and increased moisture contents.

Nutrient uptake

Irrigation and N levels had significantly enhanced the uptake of N, P and K (Table 5-7). Irrigation levels I_1 and I_2, showed increased uptake of N (109.03 and 105.82 kg ha^{-1}) and (92.47 and 92.48 kg ha^{-1}), P (21.65 and 20.46 kg ha^{-1}) and K (104.5 and 106.5 kg ha^{-1}) and (89.9 and 95.1 kg ha^{-1}) during both the years over I_4. This might be due to better root growth conditioned by favourable moisture regimes, thereby resulting in higher uptake of applied nutrients. Higher uptake of P and K associated with enlarged root system and higher soil moisture regimes has also been reported by Guimera *et al.*, (1995) and Raman Murthy and Reddy (2013). Nitrogen levels N_3 recorded significantly higher uptake of N (99.15 and 99.12 kg ha^{-1}), P (19.36 and 19.40 kg ha^{-1}) and K (95.6 and 100.8 kg ha^{-1})

over N_2 and N_1. Higher availability of nutrients as well as higher yield could be attributed for the higher uptake of nutrients. These results are in line with the findings of Hara and Saha (2000), Kemal (2013) and Al-Solaimani and Bakshi (2002), who also observed higher uptake of N with the increase in N application in tomato, onion and cabbage, respectively. Interactive effect of irrigation schedules and N levels on N, P and K uptake was found to be significant. Significantly higher N, P and K uptake was observed in I_1N_3 (127.81 and 126.36 kg ha^{-1}), P (24.91 and 23.84 kg ha^{-1}) and K (120.5 and 126.7 kg ha^{-1}) and I_2N_3 (110.81 and 105.59 kg ha^{-1}), P (22.52 and 21.46 kg ha^{-1}) and K (107.6 and 107.7 kg ha^{-1}) over I_4N_1. Irrigation levels I_1 and I_2 with higher levels of N application led to higher nutrient availabilities which might have been utilized efficiently by the crop and produced higher yield resulting higher nutrient uptake. Higher uptake of N might have been due to favourable moisture regimes which in turn allowed greater proliferation of roots, thereby facilitating higher absorption of nutrients and water from the soil. Nitrogen to be available to growing crops, the soil moisture must be sufficient to allow nitrates to move to the roots. However in dry soil, optimal quantities of N could not reach to the plant roots, indicating that N utilization was influenced by soil moisture status during the growing season.

Bulb yield

Irrigation levels exerted significant impact on bulb yield of onion (Table 8). Significantly higher (407.8 q ha^{-1} and 410.7 q ha^{-1}) and lower (327.0 q ha^{-1} and 307.8 q ha^{-1}) bulb yield was recorded under I_1 and I_4, respectively as compared to other irrigation levels, during both the years of study. Among N levels, maximum bulb yield (406.5 q ha^{-1} and 408.8 kg ha^{-1}) and minimum (336.8 q ha^{-1} and 332.7q ha^{-1}) was recorded under N_3 and N_1 levels, during both the years of study. In case of interaction (I×N) significantly higher bulb yield (462.7 q ha^{-1} and 471.3 q ha^{-1}) was recorded under I_1N_3 and lower (306.0 q ha^{-1} and 305.3 q ha^{-1}) under I_4N_1 which was found to be at par with I_4N_2 (316.7 q ha^{-1} and 305.3 q ha^{-1}) treatment combination during both the years. Pooled analysis showed that the effect of irrigation and N levels was significant and the trend was almost similar during both the years of study. Maximum (409.2 q ha^{-1}) and minimum bulb yield (317.4 q ha^{-1}) was recorded under I_1 and I_4, respectively over other irrigation levels, whereas maximum bulb yield (407.7 q ha^{-1}) and minimum bulb yield (334.3 q ha^{-1}) was recorded under N_3 and $N_{1,}$ respectively as compared to other N levels. In case of interaction of irrigation and N levels (I×N) maximum bulb yield (467.0 q ha^{-1}) was recorded under 1.2 IW/CPE ratio and supplied with 125 per cent N (I_1N_3) and minimum (303.7 q ha^{-1}) under 0.6 IW/CPE ratio with 75 per cent N (I_4N_1). The highest bulb yield at irrigation levels I_1 and I_2 might be due to optimum soil moisture regimes (Table 1) throughout the growing period which might have facilitated greater nutrient uptake and proper soil physical environment to help the plants to put forth better vegetative growth, leading to higher bulb growth and yield. The present results are in accordance with the earlier findings of Lorenz and Maynard (1980), Adentuji (1990) and Lingaiah *et al.,* (2005) and Bungard *et al.*, (1999) in onion. In the present findings also, better performance of all the components as a result of optimum soil moisture provided by appropriate quantity of water at desired interval might have resulted in steady active plant growth and maximum possible yield. Rathore and Singh (2009) also emphasized the importance of irrigation at appropriate time as plant tissue contains more than 95 per cent of water which should be maintained for keeping the plant photosynthetically active resulting in proper growth and development and ultimately yield. Higher yield of onion in N_3 might be due to complete solubility, mobilization and availability of N at regular interval in required quantity due to split application. Similar results were also reported by Sharma *et al.,* (2009) in onion, Gulsum *et al.,* (2010) in lettuce, Goudra and Rokhade (2001) in cabbage, Alam *et al.,* (2010) in carrot, Singh *et al.,* (2010) in potato and Tolga *et al.,* (2010) in broccoli. Favourable effects of N on yield of tomato and eggplant have also been reported by Hegde and Srinivas (1989) and Rahman *et al.,* (2007). The reasons suggested for such a response was that optimum N application increased growth parameters, which in return synthesized more plant metabolites thereby increased crop yield.

Table.1 Effect of irrigation levels on soil moisture contents (0-7.5 cm and 7.5-15 cm depths) during the year 2016 and 2017

Treatments			Moisture contents (%,w/w)			
			0-7.5 cm depth		7.5-15 cm depth	
			Before irrigation	After Irrigation	Before irrigation	After Irrigation
I_1	Range	2016	10.92-16.44	22.46-27.24	11.44-17.62	**18.14-24.32**
		2017	11.77-16.69	22.78-28.45	12.52-17.92	**19.74-25.12**
	Mean	2016	14.96	25.94	16.22	**22.80**
		2017	15.10	26.27	16.46	**23.60**
I_2	Range	2016	10.22-14.08	21.12-26.84	11.14-15.96	**18.14-23.94**
		2017	10.52-14.12	21.26-27.14	11.84-15.76	**18.66-24.24**
	Mean	2016	13.12	24.14	14.20	**21.86**
		2017	13.24	24.58	14.16	**22.26**
I_3	Range	2016	10.02-13.12	20.88-24.24	10.08-13.34	**17.16-21.16**
		2017	10.16-13.18	20.18-24.44	10.84-13.74	**17.46-21.96**
	Mean	2016	11.04	22.48	12.36	**18.86**
		2017	11.12	22.84	12.64	**19.18**
I_4	Range	2016	9.84-11.22	17.79-21.88	9.96-12.54	**15.78-19.12**
		2017	9.64-11.04	18.79-22.97	10.06-12.87	**16.48-19.72**
	Mean	2016	10.48	19.72	11.24	**17.60**
		2017	**10.34**	**20.88**	**11.46**	**18.10**

Table.2 Effect of irrigation and N levels on available soil N (kg ha^{-1})

Treatments	2015-16				2016-17				Pooled			
N / I	N_1	N_2	N_3	Mean	N_1	N_2	N_3	Mean	N_1	N_2	N_3	Mean
I_1	325.0	371.6	400.0	365.5	301.3	368.7	402.7	357.6	313.2	370.2	401.3	361.6
I_2	282.0	368.3	393.3	347.9	289.3	351.0	385.3	341.9	285.7	359.7	389.3	344.9
I_3	246.0	358.0	377.0	327.0	266.7	315.3	336.0	306.0	256.3	336.7	356.5	316.5
I_4	236.0	330.7	372.0	312.9	265.0	298.7	309.7	291.1	250.5	314.7	340.8	302.0
Mean	272.5	357.2	385.9	338.3	280.6	333.4	358.4	324.4	276.4	345.3	372.0	331.2
$CD_{(0.05)}$												
I		7.23				7.03				4.22		
N		6.27				6.09				3.65		
I×N		12.53				12.18				7.31		

I_1: (1.2 IW/CPE ratio), I_2: (1.0 IW/CPE ratio), I_3: (0.8 IW/CPE ratio), I_4: (0.6 IW/CPE ratio)
N_1: 75 % of recommended dose of N, N_2: Recommended dose of N, N_3: 125 % of recommended dose of N

Table.3 Effect of irrigation and N levels on available soil P (kg ha^{-1})

Treatments	2015-16				2016-17				Pooled			
N / I	N_1	N_2	N_3	Mean	N_1	N_2	N_3	Mean	N_1	N_2	N_3	Mean
I_1	50.00	58.03	63.67	57.23	46.40	53.93	59.53	53.29	48.20	55.98	61.60	55.26
I_2	47.20	53.93	61.13	54.09	44.13	51.13	57.13	50.80	45.67	52.53	59.13	52.44
I_3	43.93	46.63	53.33	47.97	40.40	42.83	47.67	43.63	42.17	44.73	50.50	45.80
I_4	38.00	45.07	36.83	39.97	37.67	40.80	33.03	37.17	37.83	42.93	34.93	38.57
Mean	44.78	50.92	53.74	49.81	42.15	47.18	49.34	46.22	43.47	49.05	51.54	48.02
$CD_{(0.05)}$												
I		1.68				1.50				1.48		
N		1.46				1.30				1.28		
I×N		2.91				2.60				2.56		

I_1: (1.2 IW/CPE ratio), I_2: (1.0 IW/CPE ratio), I_3: (0.8 IW/CPE ratio), I_4: (0.6 IW/CPE ratio)
N_1: 75 % of recommended dose of N, N_2: Recommended dose of N, N_3: 125 % of recommended dose of N

Table.4 Effect of irrigation and N levels on available soil K (kg ha^{-1})

Treatments	2015-16				2016-17				Pooled			
N / I	N_1	N_2	N_3	Mean	N_1	N_2	N_3	Mean	N_1	N_2	N_3	Mean
I_1	336.0	384.7	410.7	377.1	342.7	390.7	396.9	376.6	339.3	387.5	403.8	376.9
I_2	316.3	374.0	387.6	359.3	323.5	367.6	377.7	356.1	319.9	370.8	382.4	357.7
I_3	289.5	350.7	356.7	332.3	283.6	341.3	358.3	327.8	286.6	346.0	357.5	330.0
I_4	270.3	330.7	343.3	314.7	277.0	321.6	337.9	312.2	273.7	326.2	340.5	313.4
Mean	303.1	360.0	374.5	345.9	306.7	355.2	367.6	343.2	304.9	357.6	371.1	344.5
$CD_{(0.05)}$												
I		3.8				2.9				2.7		
N		3.3				2.5				2.3		
I×N		6.6				5.0				4.6		

I_1: (1.2 IW/CPE ratio), I_2: (1.0 IW/CPE ratio), I_3: (0.8 IW/CPE ratio), I_4: (0.6 IW/CPE ratio)
N_1: 75 % of recommended dose of N, N_2: Recommended dose of N, N_3: 125 % of recommended dose of N

Table.5 Effect of irrigation and N levels on total N uptake (kg ha^{-1}) in onion

Treatment	2015-16				2016-17				Pooled			
I \ N	N_1	N_2	N_3	Mean	N_1	N_2	N_3	Mean	N_1	N_2	N_3	Mean
I_1	92.64	106.64	127.81	109.03	84.88	106.21	126.36	105.82	88.76	106.42	127.09	107.42
I_2	76.18	90.42	110.81	92.47	74.14	97.71	105.59	92.48	75.16	94.06	108.20	92.48
I_3	67.98	79.01	79.33	75.44	65.83	82.55	87.99	78.79	66.91	80.78	83.66	77.11
I_4	60.96	66.57	78.64	68.72	59.86	65.13	76.55	67.18	60.41	65.85	77.59	67.95
Mean	74.44	85.66	99.15	86.41	71.18	87.90	99.12	86.07	72.81	86.78	99.14	86.24
$CD_{(0.05)}$												
I		5.23				3.43				3.55		
N		4.53				2.97				3.08		
I×N		9.06				5.94				6.15		

I1: (1.2 IW/CPE ratio), I2: (1.0 IW/CPE ratio), I3: (0.8 IW/CPE ratio), I4: (0.6 IW/CPE ratio)
N1: 75 % of recommended dose of N, N2: Recommended dose of N, N3: 125 % of recommended dose of N

Table.6 Effect of irrigation and N levels on total P uptake (kg ha^{-1}) in onion

Treatment	2015-16				2016-17				Pooled			
I \ N	N_1	N_2	N_3	Mean	N_1	N_2	N_3	Mean	N_1	N_2	N_3	Mean
I_1	19.04	20.99	24.91	21.65	17.24	20.29	23.84	20.46	18.14	20.64	24.37	21.05
I_2	15.77	18.15	22.52	18.81	15.47	18.31	21.46	18.42	15.62	18.23	21.99	18.61
I_3	13.83	15.47	15.07	14.79	13.67	16.69	17.95	16.10	13.75	16.08	16.51	15.45
I_4	10.34	11.59	14.95	12.29	12.75	13.63	14.34	13.57	11.54	12.61	14.65	12.93
Mean	14.74	16.55	19.36	16.89	14.78	17.23	19.40	17.14	14.76	16.89	19.38	17.01
$CD_{(0.05)}$												
I		1.77				1.68				1.27		
N		1.53				1.46				1.09		
I×N		NS				NS				NS		

I1: (1.2 IW/CPE ratio), I2: (1.0 IW/CPE ratio), I3: (0.8 IW/CPE ratio), I4: (0.6 IW/CPE ratio)
N1: 75 % of recommended dose of N, N2: Recommended dose of N, N3: 125 % of recommended dose of N

Table.7 Effect of irrigation and N levels on total K uptake (kg ha-1) in onion

Treatment	2015-16				2016-17				Pooled			
I \ N	N_1	N_2	N_3	Mean	N_1	N_2	N_3	Mean	N_1	N_2	N_3	Mean
I_1	90.8	102.3	120.5	104.5	88.5	104.2	126.7	106.5	89.7	103.3	123.6	105.5
I_2	75.7	86.3	107.6	89.9	78.5	99.1	107.7	95.1	77.1	92.7	107.7	92.5
I_3	67.7	75.6	78.1	73.8	68.3	84.5	90.7	81.2	68.0	80.1	84.5	77.5
I_4	58.8	63.1	76.0	66.0	60.1	66.1	78.1	68.1	59.5	64.6	77.1	67.1
Mean	73.2	81.8	95.6	83.6	73.9	88.5	100.8	87.7	73.6	85.2	98.2	85.7
$CD_{(0.05)}$												
I		5.2				3.8				3.7		
N		4.5				3.3				3.2		
I×N		9.1				6.6				6.4		

I1: (1.2 IW/CPE ratio), I2: (1.0 IW/CPE ratio), I3: (0.8 IW/CPE ratio), I4: (0.6 IW/CPE ratio)
N1: 75 % of recommended dose of N, N2: Recommended dose of N, N3: 125 % of recommended dose of N

Table.8 Effect of irrigation and N levels on bulb yield (q ha^{-1})

Treatments	2015-16				2016-17				Pooled			
N / I	N_1	N_2	N_3	Mean	N_1	N_2	N_3	Mean	N_1	N_2	N_3	Mean
I_1	370.0	390.7	462.7	407.8	354.7	406.0	471.3	410.7	362.3	398.3	467.0	409.2
I_2	346.7	364.0	423.7	378.1	350.7	373.3	447.3	390.4	348.7	368.7	435.5	384.3
I_3	324.7	340.0	381.3	348.7	320.0	357.3	389.3	355.6	322.3	348.7	385.3	352.1
I_4	306.0	316.7	358.3	327.0	290.7	305.3	327.3	307.8	303.7	305.7	342.8	317.4
Mean	336.8	352.8	406.5	365.4	329.0	360.5	408.8	366.1	334.3	355.3	407.7	365.8
$CD_{(0.05)}$												
I		10.2				13.5				7.1		
N		8.9				11.7				6.2		
I×N		17.7				23.3				12.4		

I1: (1.2 IW/CPE ratio), I2: (1.0 IW/CPE ratio), I3: (0.8 IW/CPE ratio), I4: (0.6 IW/CPE ratio)
N1: 75 % of recommended dose of N, N2: Recommended dose of N, N3: 125 % of recommended dose of N

Table.9 Effect of irrigation levels on water requirement and water use efficiency

Treatments	Irrigation water applied (cm)		Effective rainfall (cm)		Profile water use (cm)		Total water requirement (IWA+ER+profie water use) (cm)		TWR (Average) (cm)	WUE kg ha^{-1} mm^{-1})		WUE (kg ha^{-1} mm^{-1}) (Average)
	2016	2017	2016	2017	2016	2017	2016	2017		2016	2017	
I1	27.5	31.5	5.96	7.26	1.96	0.38	35.42	39.14	37.28	115.1	104.9	**110.0**
I2	23.5(	27.5	8.84	8.26	2.11	1.53	34.45	37.29	35.87	109.7	104.6	**107.0**
I3	19.5	23.5	11.5	9.26	3.40	3.49	34.40	36.25	35.32	101.3	98.0	**99.7**
I4	**15.5**	**19.5**	**13.8**	**9.36**	**4.20**	**4.24**	**33.50**	**31.10**	**32.30**	**97.6**	**92.0**	**94.8**

*Figures in parentheses are the number of irrigations applied

Table.10 Effect of irrigation and N levels on water use efficiency (kg ha^{-1} mm^{-1}) in onion

Treatment	2015-16				2016-17				Pooled			
N / I	N_1	N_2	N_3	Mean	N_1	N_2	N_3	Mean	N_1	N_2	N_3	Mean
I_1	104.4	110.3	130.6	115.1	90.6	103.7	120.4	104.9	97.5	107.0	125.5	110.0
I_2	100.6	105.6	122.9	109.7	94.0	100.1	119.9	104.6	97.3	102.8	121.4	107.1
I_3	94.3	98.8	110.8	101.3	88.2	98.5	117.3	101.2	91.2	98.6	114.0	101.2
I_4	91.3	94.5	106.9	97.5	93.4	98.1	110.2	100.5	92.3	96.3	108.5	99.0
Mean	97.6	102.3	117.8	105.9	91.5	100.1	116.9	102.8	94.5	101.1	117.3	104.3
$CD_{(0.05)}$												
I		5.2				3.8				3.7		
N		4.5				3.3				3.2		
I×N		9.1				6.6				6.4		

I1: (1.2 IW/CPE ratio), I2: (1.0 IW/CPE ratio), I3: (0.8 IW/CPE ratio), I4: (0.6 IW/CPE ratio)
N1: 75 % of recommended dose of N, N2: Recommended dose of N, N3: 125 % of recommended dose of N

The interaction effect of irrigation and N levels on yield of onion was found to be significant (Table 8). The onion yield increased with higher frequency of irrigation and increasing N levels.

The response of yield to high amounts of water and N application could be attributed to the favorable effect on the availability of nutrients to the plant roots, which improves the growth of the crop. Significant increase in yield due to higher N application might also be due to increased photosynthesis as N is a major constituent of chlorophyll molecule which plays an important role in photosynthesis. Increased photosynthesis results in accumulation of carbohydrates in the bulb and ultimately enhanced the plant growth and hence the yield [Neerja *et al.,* (1999) in onion and Kemal (2014) in shallot].

These results further get support from the findings of Sanchez (2000) in lettuce, Goudra and Rokhade (2001) in cabbage, Rahman (2007) in tomato and Bozkurt *et al.,* (2011) in cauliflower. Better expression of growth and yield under higher quantum of irrigation and N were also reported by Singh *et al.,* (2010) in potato because of complimentary effect of nutrient availabilities to the plants.

Total water requirement

The crop water requirement increased with frequency of irrigations (Table 9). The highest and almost equal water requirement during 2015-16 being 35.42 cm and 34.45 cm was recorded under I_1 and I_2 levels, respectively and lowest under I_4 (33.50 cm). During second year, water requirement was comparatively higher but the trend was similar to first year of study and highest water requirement (39.14 and 37.29 cm) was recorded under I_1 and I_2 and lowest (31.10 cm) under I_4 irrigation level. On the basis of average of two years, highest (37.28 cm) total water requirement was noted under I_1 irrigation level which was very closely followed by I_2 (35.87 cm) and I_3 (35.32 cm) and lowest (32.30 cm) under I_4 level.

Water use efficiency (WUE)

It is necessary to apply irrigation judiciously to maximize crop growth and WUE. Under irrigation levels (Table 10) highest WUE (115.1 and 104.9 kg $ha^{-1}mm^{-1}$) was recorded under I_1 followed by I_2 (109.7 and 104.6 kg $ha^{-1}mm^{-1}$), I_3. (101.3 and 101.2 kg ha^{-1} mm^{-1}) and lowest (97.5 and 100.5 kg ha^{-1} mm^{-1}) was recorded under I_4 level, during the year 2015-16 and 2016-17, respectively. Among N levels, highest WUE was noticed under N_3 (117.8 and 116.9 kg $ha^{-1}mm^{-1}$) and lowest under N_1 (97.6 and 91.5 kg $ha^{-1}mm^{-1}$) during the years 2015-16 and 2016-17. Among the treatment combinations, highest WUE was recorded under I_1N_3 (130.6 and 120.4 kg ha^{-1} mm^{-1}) followed by I_2N_3 (122.9 and 119.9 kg ha^{-1} mm^{-1}) and lowest under I_4N_1 (91.3 and 93.4 kg ha^{-1} mm^{-1}) during both the years of study. As the WUE is the ratio of yield to that of water applied, comparatively higher yield of onion under I_1 and I_2 (Table 8) gave higher WUE and the increase could be attributed to favourable effect of moisture regimes. Many earlier researchers have also reported higher WUE with the increase in irrigation water applied in groundnut, onion, green gram and cabbage (Taha and Gulati, 2001; Bandyopadhyay *et al.,* 2003; Idnani and Gautam, 2008; Nyatuame *et al.,* 2013).

In conclusion, efficient irrigation level is necessary for maintaining optimum soil moisture regimes for providing favourable environment for nutrient availabilities and their uptake. The study has led to a conclusion that for maximizing growth and productivity of onion in Himachal Pradesh, the integration of irrigation level 1.0 IW/CPE with an application of 125 per cent of recommended dose of N (125 kg ha^{-1}) is best as it gave higher water use efficiency (109.7 and 104.6 kg ha^{-1} mm^{-1}) with total water requirement of (34.40 and 36.25 cm) during both the years.

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