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Assessing the performance of irrigation and nitrogen fertigation on yield, water use efficiency, nitrogen use efficiency and benefit-cost ratio of onion

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ABSTRACT

The amount of water allotted for agriculture is gradually declining due to rising demands in the industrial and municipal sectors. Reduced water availability affects irrigation, which is the primary necessity for agriculture. As the increasing population and climate change pose new challenges, there is a growing need to boost food production while conserving water resources in agriculture. Drip irrigation is one proposed method that enables to maintenance or even improvement of crop yields by utilizing less amount of water and nutrients. Therefore, the present field study was carried out during the two winter seasons of 2016-17 and 2017-18 in a split-plot design having drip irrigation treatments (60, 80, 100, and 120% CPE) as main plot and nitrogen fertigation treatment (75, 100, 125 and 150 kg/ha) as sub-main plot for onion cultivation. The highest fresh and dry weight of bulb (63.18 and 73.20 g/bulb; 10.90 and 11.04 g/bulb, respectively) as well as marketable bulb yield (285.60 and 301.17 q/ha) were achieved when irrigation water was applied at 100% CPE in combination with nitrogen application @ 125 kg/ha through fertigation, while, the lowest fresh and dry weight of bulb (42.00 and 45.34 g/bulb) along with marketable bulb yield (137.15 and 142.15 q/ha) were observed where the irrigation was given at 60% CPE in combination with 75 kg/ha nitrogen application through fertigation during 2016-17 and 2017-18. However, the highest water use efficiency (59.20 and 60.60 kg/ha/mm) was recorded where the irrigation water was given at 60% CPE through drip. In contrast, the highest nitrogen use efficiency was recorded with the application of 75 kg nitrogen through fertigation (263.53 and 259.80 kg/ha), surpassing the results of other treatments. In conclusion, farmers can get better yields and profitability by adopting drip irrigation at 100% cumulative pan evaporation and 125 kg/ha nitrogen fertigation levels. This study would shed light on the impact of drip irrigation system among the researchers, which could be utilized for further strengthening the drip irrigation system in onion farming.

Keywords: *Nitrogen fertigation, irrigation, bulb yield, water use efficiency and nitrogen use efficiency, net return and benefit-cost ratio*

Introduction

The world's population is constantly growing, and the industrial, municipal, and agricultural sectors' demands for more water supply put a lot of strain on renewable water supplies. As a result, the agricultural sector must make efficient use of irrigation water to meet the food demand of the growing population [1 and 9]. Therefore, it is important to develop irrigation strategies that can be utilized by farmers and extensive service provider to ensure the sustainable management of limited water resources available for agricultural purposes [6]. For more efficient and sensible uses of finite water supplies, irrigation systems and scheduling may be modified. New irrigation scheduling techniques must be created, ones that guarantee the best possible use of the water allotted, rather than ones that are based on the complete crop water requirement. It is essential to meticulously manage the quantity of irrigation water utilized to attain optimal yield and quality.

Surface irrigation, which uses water inefficiently but is comparatively cheap, is used to cultivate the majority of onions in India. A novel method for raising agricultural output and improving water use efficiency is drip irrigation [3 and 11]. Onions exhibit varying water needs throughout their developmental stages, with the establishment of a robust early canopy being essential for ideal bulb production [13]. The bulb initiation stage is the most critical growth phase for onion crops, occurring 20 to 30 days after transplanting. During this period, onion plants exhibit sensitive to water stress [7].

The cost of fertilizers is increasing daily. Therefore, research into the effective utilization of this input is deemed vital. This can be accomplished by implementing an effective drip watering system. Fertigation is the process of applying fertilizer via an irrigation system. Among the key features of this technique that have made it so well-liked globally are higher yields, better produce quality, more efficient use of fertilizer and irrigation, and preservation of the soil ecosystem. The best method for this is to combine fertilization and irrigation, with irrigation water serving as a conduit for the nutrients that crops need. Onion (*Allium cepa* L.) is one of the most vital and prominent irrigated vegetable crops cultivated widely across India. The amount of irrigation water applied has a significant impact on it [5].

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Therefore, the following objectives were established for the current investigation:

1. To evaluate the water and nitrogen use efficiency under drip system

2. To work out the benefit-cost ratio associated with drip fertigation system

Materials and Methods

Experimental site

The study was conducted at Vegetable Research Farm of Chaudhary Charan Singh Haryana Agricultural University Hisar, Haryana (India). This site is positioned at 29°10' N latitude and 75°46' E longitude with an elevation of 215.2 meters above mean sea level. The locale of Hisar has a typical semi-arid climate, characterized by very high temperatures in the summer, reaching up to 47 ºC, and cold conditions in the winter, with temperatures dropping to 0 ºC. The cumulative rainfall of 400 mm occurs as a result of the south-west monsoon from July to September. The mean monthly values for important weather parameters (rainfall, air temperature, relative humidity and evaporation) recorded from the Meteorological Observatory at Research Farm, Hisar during the crop season (January to May, 2017 and January to May, 2018) are given in Fig b. The soil was well-drained sandy loam in texture with pH of 8.3.

Treatment and layout

The study comprised four distinct levels of drip irrigation: I_1 (60% CPE), I_2 (80% CPE), I_3 (100% CPE) and I_4 (120% CPE). Additionally, it incorporated four levels of nitrogen fertigation, namely N_1 (75 kg/ha), N_2 (100 kg/ha), N_3 (125 kg/ha), and N_4 (150 kg/ha), along with a control treatment that utilized the recommended nitrogen dosage and furrow irrigation. This resulted in a total of seventeen different treatments.

The treatments were replicated three times resulting in 51 plots. Hence, the experiment was evaluated in split plot design with drip irrigation serving as the main treatment and fertigation as secondary treatment. The field plots of each treatment had areas of 3.3 m^2 (6 m long and 55 cm wide) on which three rows of onion seedlings were transplanted at 15 cm distance between row to row and 10 cm between plant to plant in 2017 and 2018, respectively. The plots designated for each treatment replication measured 3.3 m^2 (6 m long and 55 cm wide). Within these plots, three rows of onion seedlings were transplanted, maintaining a distance of 15 cm between each row and 10 cm between individual plants during the years 2017 and 2018. Before transplanting, the irrigation water was applied by drip laterals which were placed in the center of the bed. The emitters were spaced at 30 cm with a 1.5 L h^{-1} discharge rate. Each plot was equipped with a valve and a water meter to control and measure the distribution of water. Additionally, a pressure gauge installed on the main pipe was also employed to manually regulate the operating pressure at the beginning of each irrigation session.

Fig a. Field trail

Irrigation and fertigation schedule

During growing seasons of onion, the required amount of water was delivered via drip irrigation when cumulative pan evaporation (CPE) attained the value of 10 mm. The fertilizers utilized in the experiment were urea, single super phosphate and muriate of potash as a source of nitrogen, phosphorus and potassium, respectively. The full dose of phosphorus (50 kg/ha) and potassium (25 kg/ha) were applied during the final preparation of the field. The fertigation of various nitrogen doses (75, 100, 125, and 150 kg/ha) was started from 15 days after transplanting to 75 days after transplanting at fifteen days intervals. All agronomic practices were kept uniform across all treatments.

Data collection and analysis

Irrigation was ceased two weeks before to harvesting when 75% of the tops began to droop, yet before the foliage had completely dried in all treatments. The data on average fresh and dry weight of bulb, dry matter content and different grades bulb yield (>50, 40-50, 30-40 and <30 mm diameter) were recorded after proper curing. The water use efficiency and nitrogen use efficiency were calculated by dividing onion bulb yield with the total amount of water and nitrogen applied to the crop, respectively. The collected data were statistically analysed according to the method suggested by Sheoran [18]. The probability level for determination of significance was 5%.

Results and Discussion

The data on average fresh and dry weights of the bulb are illustrated in Figures c and d. The highest fresh and dry weights of the bulb (63.18 and 73.20 g; 10.90 and 11.04 g, respectively) were recorded when irrigation water was applied at 100% of the cumulative pan evaporation in conjunction with the application of 125 kg/ha nitrogen through drip in comparison to the rest of the treatment combination during both growing year 2016-17 and 2017-18. But the highest dry matter content of bulb (17.26 %) was observed with the application of irrigation water at 100% CPE and 125 kg/ha nitrogen in first years but in second year, it was not significantly affected with different treatment combinations (Fig e). This may be attributed to the sufficient provision of water and nutrients by drip irrigation in proximity to the root zone, which ensured an optimal soil moisture environment in the crop root zone during the entire growth period. Application of water and nutrients through drip system enhances the absorption of nutrients from the soil and promote the synthesis of carbohydrates by improving vegetative growth, which in turn increases fresh as well as dry weight of onion bulb. This finding aligns with the research conducted by Yadav *et al*. [21], who observed that the highest fresh and dry weight of onion bulbs was achieved with micro-sprinkler irrigation at 100% ETc in contrast to 85% ETc. Additionally, this outcome is consistent with drip irrigation and fertigation studies in onion [17 and 10].

The irrigation and nitrogen levels also had a significant impact on different grade sizes in both years. The highest weight of A (1.19 and 1.32 kg/m^2, respectively), B (1.10 and 1.25 kg/m^2, respectively), C grade (0.57 and 0.44 kg/m^2, respectively) and marketable bulb yield (285.60 and 301.17 q/ha) were achieved with the application of irrigation water at 100% CPE in combination with 125 kg/ha nitrogen through drip when compared to remaining treatment combination during both years of study (Fig. f, g, h and j).

But the maximum unmarketable bulb yield (32.67 and 27.15 q/ha) was observed when the lesser amount of water (60% CPE) and nitrogen (75 kg/ha) was applied by drip system as compared to the remaining treatment combinations (Fig. i). This might be due to maintenance of adequate soil moisture near to root zone and sufficient amount of nutrients in the soil solution. The bulb sizes were directly related to the amount of irrigation water applied [12]. The crop needed a higher rate of nitrogen to maximize the yield when an adequate amount of irrigation water was applied [15]. Similar results were shown in onion and garlic [4], [5] and [8].

Deficit irrigation can enhance the ratio of crop yield to water consumption that exhibit tolerance to water stress during certain growth stages. This enhancement can be achieved by minimizing water loss due to unproductive evaporation, enhancing the proportion of marketable yield compared to total biomass generated, or optimizing the ratio of total biomass production to transpiration through crop hardening. However, the impact of the relationship between biomass production and crop transpiration is observed as limited [6].

Irrigation and nitrogen scheduling significantly affected the water and nitrogen use efficiency during the growing season of crop (Figures k and l). The water use efficiency (64.86 and 69.12 kg/mm) was observed highest at 60% CPE when compared to the higher levels of irrigation in both years, respectively. This might be due to a smaller percentage increase in yield relative to the increase in seasonal water applied. The results were similar to those presented earlier by [3], [13] and [8]. During both years of study, the highest nitrogen use efficiency (296.33 and 281.70 kg/kg) was achieved with the application of 75 kg/ha nitrogen through drip when compared to the other higher levels of nitrogen fertigation. This phenomenon may be attributed due to the enhanced and timely provision of moisture and nutrients, facilitated by the frequent application of small, precise quantities of water under drip irrigation throughout the growing period. Such practices help to retain nitrogen within the root zone, thereby improving nitrogen use efficiency [19].

The data on net returns and the benefit-cost ratio is illustrated in Table 1 (a) and (b), which indicates a significant increase as the irrigation (60 to 100% CPE) and nitrogen fertigation levels (75 to 125 kg/ha) increased during both years of study. However, a decline was observed with any further escalation in both irrigation and nitrogen levels. The highest net returns of 341,973.74 and 365,529.09 Rs./ha along with benefit-cost ratios of 3.35 and 3.62, were achieved with the combined application of irrigation (100 % CPE) and nitrogen (125 kg/ha) through drip irrigation. In contrast, the lowest net returns of 156,907.53 and 156,796.53 Rs./ha as well as benefit-cost ratios of 1.60 and 1.61, were recorded with the lesser amount of water (60% CPE) and nitrogen (75 kg/ha) apllied through drip during both years of study. This result is consistent with the finding of Reddy *et al*. [16] and Chauhan *et al*. [2] reported that the highest net return and benefit-cost ratio was observed under drip irrigation at 80% ET followed by irrigation at 100% ET.

Conclusion

Water is a major limiting factor for crop production in North-Western region of India (Haryana). Therefore, drip irrigation is a suitable and most efficient method for sustainable production in water scare areas. The results obtained from the present investigation inferred that drip irrigation at 100% of CPE plus 125 kg/ha nitrogen through fertigation helped to obtain the higher fresh weight, marketable bulb yield and large grade size bulb that is appropriate for commercial onion farming in the Northwestern region of India's agroclimatic condition. In comparison with surface irrigation, drip irrigation proved to save a significant amount of irrigation water (25.32 to 62.66 %), while also contributing to conserve water and nutrients in onion cultivation.

Future scope

The drip irrigation and fertigation in onion cultivation offering high water and nutrient use efficiency, increasing yields and improving the nutritional quality of onions, while also reducing labor costs, weeds and disease incidence. Hence, this precision agriculture technologies will be very effective for further research in the subject and to optimize water and nutrient management strategies may enhance resource use efficiency. Such advancements could further refine sustainable cultivation practices, ensuring agricultural productivity while addressing the challenges posed by climate change and limited land resources.

Acknowledgment

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Conflict of interest

The authors did not disclose any potential conflicts of interest that could have influenced the research, authorship and publication of this article.

Table 1 (a): Economics of various treatments in 2016-17

Irrigation levels (% CPE)	Nitrogen levels (kg/ha)	Common cost (Rs./ha)	Treatment cost (Rs./ha)	Total cost (Rs./ha)	Yield (q/ha)	Gross return (Rs./ha)	Net return (Rs./ha)	B:C ratio
I_1 (60)	75	91332.73	6490.95	97823.68	169.82	254731.21	156907.53	1.60
	100	91332.73	6798.75	98131.48	180.67	271011.82	172880.34	1.76
	125	91332.73	7106.55	98439.28	206.14	309212.12	210772.84	2.14
	150	91332.73	7420.05	98752.78	195.92	293885.38	195132.60	1.98
I_2 (80)	75	91332.73	8344.90	99677.63	186.04	279054.55	179376.92	1.80
	100	91332.73	8652.70	99985.43	215.38	323075.76	223090.33	2.23
	125	91332.73	8960.50	100293.23	241.35	362030.30	261737.07	2.61
	150	91332.73	9274.00	100606.73	229.63	344439.39	243832.66	2.42
I_3 (100)	75	91332.73	10198.85	101531.58	222.24	333366.67	231835.09	2.28
	100	91332.73	10506.65	101839.38	249.55	374318.18	272478.80	2.68
	125	91332.73	10814.45	102147.18	296.08	444120.92	341973.74	3.35
	150	91332.73	11127.95	102460.68	275.40	413106.06	310645.38	3.03

I₄ (120)	75	91332.73	12052.80	103385.53	212.49	318742.42	215356.89	2.08
	100	91332.73	12360.60	103693.33	231.24	346862.12	243168.79	2.35
	125	91332.73	12668.40	104001.13	273.87	410800.00	306798.87	2.95
	150	91332.73	12981.90	104314.63	262.11	393160.38	288845.75	2.77
Control	125	95449.4	1544.7	96994.1	190.25	285375.00	192497.57	2.07

Price of urea = Rs. 5.70 Price of onion bulb = Rs.15/kg
Price of onion seed = Rs. 1000/kg

Table 1 (b): Economics of various treatments in 2017-18

Irrigation levels (% CPE)	Nitrogen levels (kg/ha)	Common cost (Rs./ha)	Treatment cost (Rs./ha)	Total cost (Rs./ha)	Yield (q/ha)	Gross return (Rs./ha)	Net return (Rs./ha)	B:C ratio
I₁ (60)	75	91332.73	5822.10	97154.83	169.30	253951.36	156796.53	1.61
	100	91332.73	6129.90	97462.63	179.91	269867.91	172405.28	1.77
	125	91332.73	6437.70	97770.43	219.68	329515.15	231744.72	2.37
	150	91332.73	6751.20	98083.93	201.44	302157.58	204073.65	2.08
I₂ (80)	75	91332.73	7453.10	98785.83	192.24	288359.27	189573.44	1.92
	100	91332.73	7760.90	99093.63	217.06	325596.82	226503.19	2.29
	125	91332.73	8068.70	99401.43	256.48	384714.85	285313.42	2.87
	150	91332.73	8382.20	99714.93	239.30	358952.12	259237.19	2.60
I₃ (100)	75	91332.73	9084.10	100416.83	211.28	316915.15	216498.32	2.16
	100	91332.73	9391.90	100724.63	263.11	394666.97	293942.34	2.92
	125	91332.73	9699.70	101032.43	311.04	466561.52	365529.09	3.62
	150	91332.73	10013.20	101345.93	293.73	440588.03	339242.10	3.35
I₄ (120)	75	91332.73	10715.10	102047.83	206.58	309865.76	207817.93	2.04
	100	91332.73	11022.90	102355.63	254.29	381429.79	279074.16	2.73
	125	91332.73	11330.70	102663.43	298.42	447635.76	344972.33	3.36
	150	91332.73	11644.20	102976.93	284.52	426779.55	323802.62	3.14
Control	125	95449.4	1544.7	96994.1	196.73	295095.00	202217.57	2.18

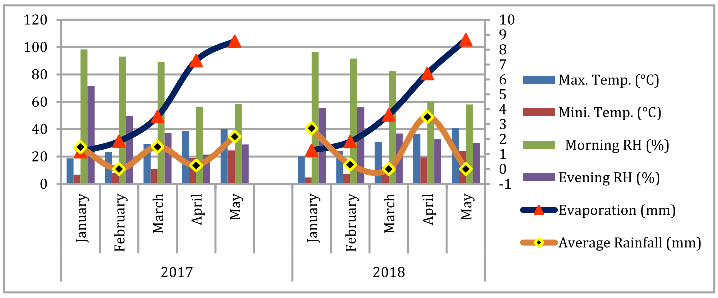

Fig b: Mean weekly meteorological data recorded during crop season 2017 and 2018

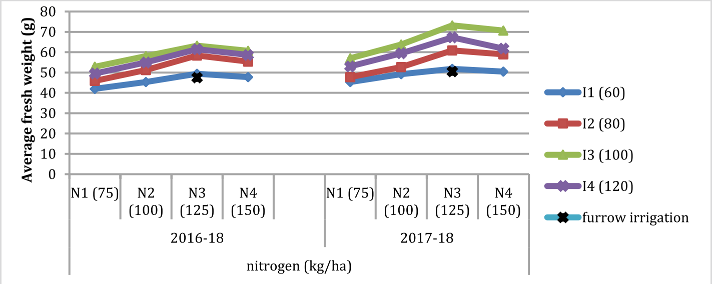

Fig c: Effect of irrigation and nitrogen levels on average fresh weight of bulb (g)

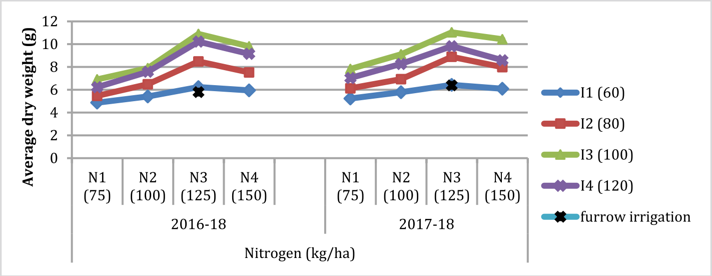

Fig d: Effect of irrigation and nitrogen levels on average dry weight of bulb (g)

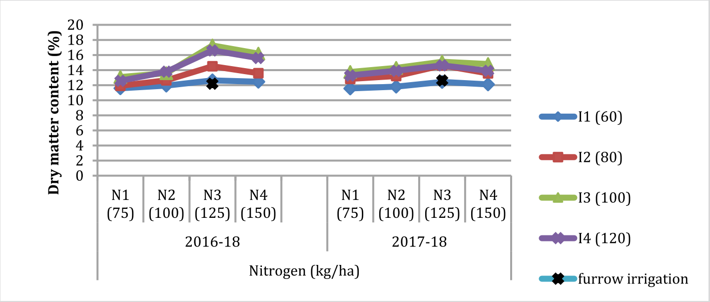

Fig e: Effect of irrigation and nitrogen levels on dry matter content of onion bulb (%)

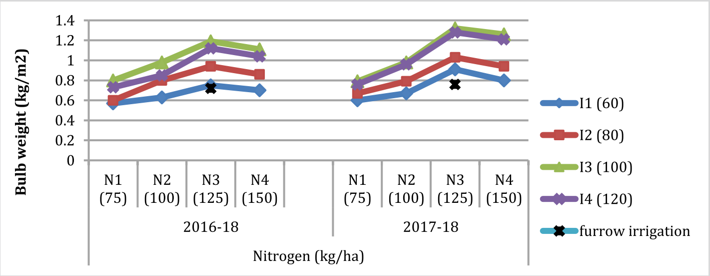

Fig f: Effect of irrigation and nitrogen levels on weight of > 5.0 cm size bulb (kg/m^2)

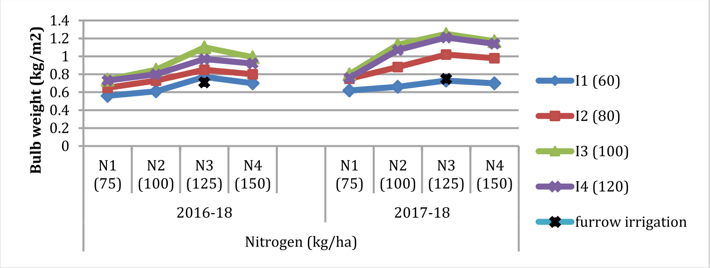

Fig g: Effect of irrigation and nitrogen levels on weight of 4.0-5.0 cm size bulbs (kg/m^2)

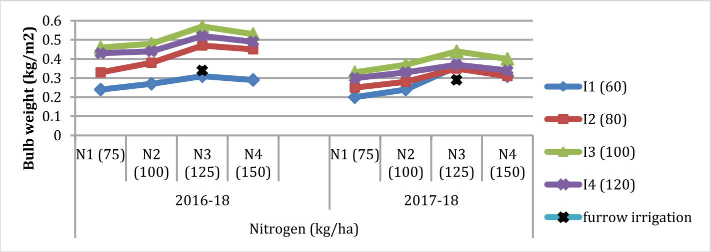

Fig h: Effect of irrigation and nitrogen levels on weight of 3.0-4.0 cm size bulbs (kg/m^2)

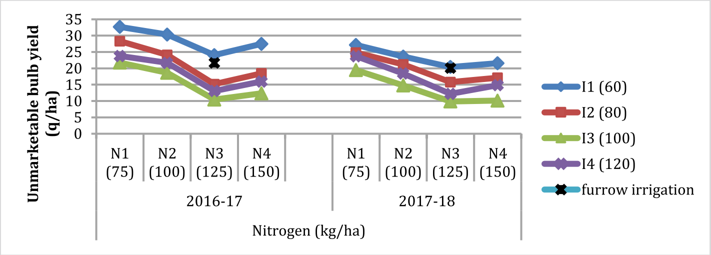

Fig i: Effect of irrigation and nitrogen levels on unmarketable bulb yield of onion (q/ha)

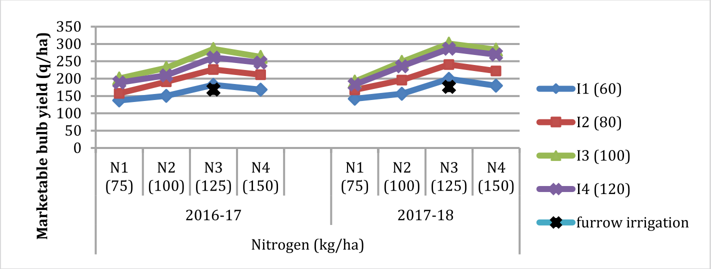

Fig j: Effect of irrigation and nitrogen levels on marketable bulb yield of onion (q/ha)

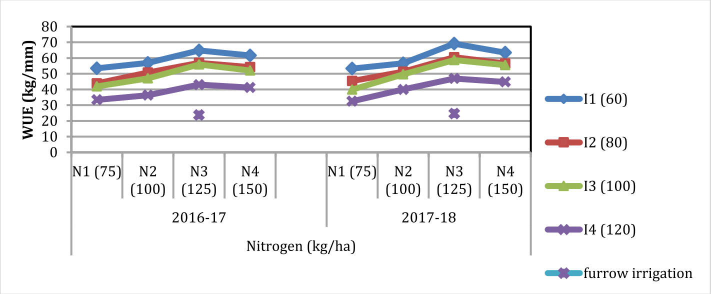

Fig k: Effect of irrigation and nitrogen levels on water use efficiency (kg/mm) of onion

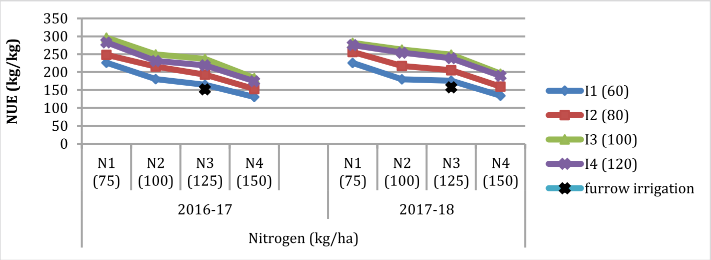

Fig l: Effect of irrigation and nitrogen levels on nitrogen use efficiency (kg/kg) of onion

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