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Response of tomato (*Solanum lycopersicum*) to varying levels of irrigation and nitrogen under trickle fertigation

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ABSTRACT

An experiment was conducted during 2022 and 2023 at Lovely Professional University, Jalandhar, Punjab to study the response of tomato (*Solanum lycopersicum* L.) to 3 irrigation levels [I_1, 70%; I_2, 85% and I_3, 100% of IWR] and 3 nitrogen fertilization levels [N_1, 70%; N_2, 85% and N_3, 100% of RDN] in split plot design. On individual effect basis, the fruit yield first increased with the increase in amount of applied irrigation water in I_2 (95.6 t/ha) and then decreased in I_3 (93.5 t/ha). Irrigation water use efficiency (IWUE) was the highest in I_2 (3.73 t/ha-cm). Plant growth, tomato yield and IWUE were significantly higher in N_2 than that were found in N_1 and N_3. Nitrogen use efficiency (NUE) decreased with increasing nitrogen levels (N_2 and N_3) but it increased with increasing amount of water applied (I_3). The treatments having deficit irrigation level as I_1 and I_2, significantly enhanced the lycopene content (27 to 33 μg/g) and reduced the nitrate content (74 to 95 mg/kg**)** in the fruit over full irrigation level I_3. Nitrate content was highest in N_3 (100 mg/kg). Among all the combination of irrigation and nitrogen fertilization levels the interaction of I_2N_2 (85% of IWR and RDN) was found the best to grow the drip-irrigated tomato crop. This combination gave optimum plant growth (87.5 cm), fruit yield (100 t/ha), IWUE (3.93 t/ha-cm), NUE (0.79 t/kg) and good quality fruit. The findings can be utilized for irrigation planning and nitrogen management in tomato cultivation and to conserve available fresh water resources in water scare regions of Punjab. In order to promote trickle fertigation at village level, the awareness programs for farmers could be conducted.

Keywords: Fertigation, Irrigation water use efficiency, Nitrogen, Quality, Tomato, Yield

The struggle for limited water resources among agriculture and industrial sectors has become very pensive, which pressurizes for an improvement over conventional irrigation practices for tomato (*Solanum lycopersicum* L.) cultivation. In India, tomato is popular after potato, with approximately 183.9 million tonnes of fruit yield produced on area of 8.4 million ha during each year (FAOSTAT, 2021). In Punjab, water is a major constraint to tomato production (Singhal *et al*. 2022) but growers are using conventional irrigation methods which results low water use efficiency (WUE). Drip irrigation (DI) has a potential to enhance yield and WUE (Kumar *et al*. 2021, Sharma and Singh 2023). In Punjab, it has been used for many crops (Singhal *et al*. 2021) but the studies related to the feasibility of DI for growing tomato crop in open field are limited which can be a cause of low adoption rate of DI in tomato cultivation. Nitrogen (N) is an essential nutrient for growth and potential yield. Farmers are applying recommended dose of nitrogen (RDN) through direct soil application (Kiymaz *et al.* 2015) which results low nitrogen use efficiency (NUE). However, Min *et al.* (2011) reported that NUE was only 18% for conventional methods of nitrogen application. Fertigation is an approach to supply variable doses of irrigation water and nitrogen in effective plant root zone, which enables farmers to improve the synchronization between fertilization and nutrient uptake (Jain *et al*. 2021). Kuscu *et al.* (2014) found that the high application of N in tomato increased fruit nitrate content, which is harmful to human health. Nitrogen fertilization is basically a technique by which nitrogen (through urea) can supply in soil along with water. Fewer studies have examined the issues effects water and nitrogen use efficiency, with the use of different levels of water and nitrogen fertilization (Jain *et al*. 2021). Therefore, it is imperative to optimize the application of right amount of irrigation water and nitrogen under drip irrigation for tomato growing in open field conditions of arid and semi-arid region of Punjab.

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MATERIALS AND METHODS

The experiment was conducted during 2022 and 2023 at Lovely Professional University, Jalandhar [latitude 31.25°

N; longitude 75.70° E; altitude of 280 m amsl], Punjab. The region has a humid subtropical climate. The annual mean temperature and precipitation are 23.1°C and 957 mm. The soil type in study area is sandy loam.

The raised beds (10 m × 1.5 m) were arranged in a split-plot design, with the irrigation regimes as the main plot factor and nitrogen fertilization levels as the sub-plot factor. The amount of water as per three irrigation regimes [i.e. volume of irrigation water equivalent to 70% (I_1), 85% (I_2), and 100% (I_3) of daily irrigation water requirement (IWR)] was supplied through drip irrigation in morning time. The daily IWR was calculated on the basis of daily pan evaporation data received from CLASS-A pan evaporimeter. The three level of nitrogen fertilization [i.e. 70% (N_1), 85% (N_2), and 100% (N_3) of recommended dose of nitrogen (RDN @150 kg/ha)] was supplied through drip fertigation for 15 times at 4-days interval. Each of the nine treatments had three replicates and a total of 27 plots were arranged. An impermeable fiber sheet was embedded vertically in the soil to a depth of 70 cm between each plot to prevent lateral movement of irrigation water. In each plot, the basal dose of phosphorus and potassium was supplied through broadcasting.

Crop details: The tomato (cv. Punjab Varkha Bahar 1) seedlings were transplanted in two rows over a raised bed with row to row and plant to plant spacing of 120 cm and 30 cm, respectively. The transplanting of healthy seedlings was done on 8th March during both years, after that irrigation water was supplied as per treatment (from 10th March onward).

Irrigation water requirement: The amount of irrigation water supplied per day was done by using equation 1.

$$V = \sum (Ep \times Kp \times Kc \times Sp \times Sr \times WP) \quad (1)$$

where V, Estimated irrigation water requirement (litre/day/plant); Epan, Pan Evaporation (mm/day); Kp, Pan coefficient; Kc, Crop coefficient; Sp, Plant to plant spacing (m); Sr, Row to row spacing (m); and Wp, Percentage wetted area (90%).

In this study after 24 h of irrigation water was applied, the soil samples were taken on weekly basis (10 to 20 cm depth) to check the available soil moisture content (on weight basis) in all the treatments and replications.

Crop parameter recorded: The plant height and number of branches/plant; tomato yield; weight and number of fruits/plant were recorded in all treatments. The harvest index (HI) was calculated as the ratio of dry fruit weight to the total above ground dry weight at harvest. Irrigation water and nitrogen use efficiency were also calculated.

Fruit quality analysis: 10 mature, uniform size and disease-free fruits were selected from each plot at the time of harvest. All the selected fruits were homogenized in a blender, then the lycopene and nitrates (NC) content in fruit were measured spectrophotometrically.

Irrigation water and nitrogen use efficiency: Irrigation water use efficiency (IWUE) and nitrogen use efficiency (NUE) were calculated as:

$$IWUE = \frac{C.Y}{IWR} \quad (2)$$

where IWUE, Irrigation water use efficiency (t/ha); C.Y, Crop yield (t/ha) and IWR, Total amount of irrigation water applied (cm).

$$NUE = \frac{C.Y}{N} \quad (3)$$

where NUE, Nitrogen use efficiency (t/kg); C.Y, Crop yield (t/ha) and N, Amount of nitrogen supplied (kg/ha)

Data Analysis: The data were analyzed by analysis of variance technique.

RESULTS AND DISCUSSION

Effect of integrated water and nitrogen management on growth parameters: The height of tomato plant was significantly affected by irrigation and nitrogen fertilization levels but not by interaction (Table 1). The same trend was seen for nitrogen fertilization levels. On individual effect basis, the plant height was highest in I_2 (81.9 cm) followed by I_3 (79.5 cm) and lowest in I_1 (63.1 cm). The same trend of variation in plant height was found for nitrogen levels. The number of branches/plant was significantly affected by irrigation and nitrogen fertilization levels but not by interaction ($P<0.05$). On individual effect basis, number of branches/plant first increased with increase in water level I_2 (8) and then decreased with further increase in water level (I_3). The same trend was also seen for nitrogen fertilization levels. On pooled data basis, the highest number of branches/plant was recorded in I_2N_2 and I_1N_2 with a same value (9) followed by I_2N_1 (8). Number of branches/plant was lowest in I_3N_1 and I_3N_3 with a same value (6). The same results were reported by (Javed *et al*. 2022).The plant height and number of branches were highest for a treatment having moderate deficit in irrigation water and nitrogen fertilization level (I_2 and N_2) and lowest for a treatment having severe level of water and nitrogen deficit (I_3 and N_3). It might be due to the moderate level of water and nitrogen deficit under drip irrigation may, resulted in optimum availability of moisture content (Fig. 1 and 2) and nitrogen near to plant root zone as well as minimum losses of water and nitrogen due to seepage and percolation as compared to full levels (I_1 and N_1). The appropriate soil moisture state (maintained by irrigation level I_2), along with adequate nitrogen fertilization level (N_2) may have contributed to higher photosynthesis rate and nitrogen use, supporting plant height. The better moisture absorption by roots along with nutrients under irrigation level (I_2) could have improved the photosynthesis and enabled the crop to capture a greater amount of radiant energy, which boosted photosynthate translocation to the growth portions, resulted in increased cell elongation and more number of branches per plant. The result clearly indicates that, the application of full amount of irrigation water and nitrogen (as per IWR and RDN) decline the growth of tomato crop grown under drip irrigation hence, the selection of optimum level of irrigation water and nitrogen fertilization is essential in drip irrigated tomato crop for getting the significant plant growth. Hence, on individual effects basis it can state that in selected area, the irrigation and nitrogen fertilization levels i.e. I_2 (85% of IWR) and N_2 (85% of RDN) for drip irrigated tomato crop may give more plant growth.

Effect of different treatments on yield contributing parameters and fruit yield of tomato: The average fruit weight/plant was significantly affected by the irrigation and nitrogen fertilization levels on individual and interaction basis (Table 1). The average weight of fruit/plant was increased as per increase in water and nitrogen fertilization levels ($I_1<I_2<I_3$ and $N_1<N_2< N_3$). On pooled data basis, the average number of fruits/plant, fruit yield and harvesting index first increased with increase in water level (I_2) and then decreased with further increase in water level (I_3). The same trend regarding variation in all these parameters was seen for nitrogen fertilization levels. On interaction basis, the average fruit weight/plant was found highest as 193.7 gm under treatment I_3N_3 followed by I_3N_2 (190.6 gm) and I_2N_3 (179.1 gm). Average fruit weight/plant was recorded lowest as 126.3 gm under treatment I_1N_1. The data indicates positive correlation between average fruit weight/plant and irrigation water and nitrogen fertilization levels on individual as well as interaction effect basis. The same trend was observed for nitrogen fertilization levels. On pooled data basis, the average number of fruit/plant, fruit yield and harvesting index were highest as 18, 98.7 t/ha and 0.40, respectively under treatment I_2N_2 while lowest as 15, 66.83 t/ha and 0.34 under the treatments I_3N_1, I_1N_1 and I_3N_1, respectively (Table 2 and 3). The previous studies have indicated that, a severe water stress reduced tomato yield, although depend on the amount of added nitrogen to different extents (Sun *et al.* 2013). The different water and nitrogen fertilization levels significantly affected the fruit yield. The minimum yield was in I_1 (75.28 t/ha), perhaps because the water stress accelerated flowering, which reduced the fruit's numbers and ultimately yield. The water stress under I_1 may decrease the accumulation of water in the fruit which gives less fruit weight and ultimately fruit yield. Findings are in line with Yavuz *et al.* (2015). The optimum level of nitrogen fertilization amplified the effect of irrigation. The application of 85% of RDN through drip fertigation produced the maximum yield, but the supply of 100% RDN did not continue to increase yield, which was might be due to that, the higher nitrogen application extended the crop vegetative growth and decreased the transport of photosynthates to the fruit, eventually lowering the HI. Water and nitrogen are the most important factors in tomato cultivation, and their combined effects are more important than the individual effects. The irrigation of tomato crop at 85% of daily irrigation requirement (I_2) along with nitrogen fertilization at 85% of RDN was found optimal for tomato cultivation in our study area.

Effect of integrated water and nitrogen management on quality of tomato fruit: As per pooled data, lycopene content in fruit was significantly affected by the irrigation water and nitrogen fertilization levels (on individual or interaction effects basis). Lycopene contents increased at deficit irrigation and was significantly higher in I_2 (33.72 µg/g) than that in I_1 (27.77 µg/g) and I_3 (18.09 µg/g). Lycopene contents first increased with increase in nitrogen fertilization level (N_2) and then decreased with further increase in nitrogen fertilization level (N_3). In this study the nitrates (NC) content in tomato fruit increased significantly with the increase in irrigation water and nitrogen fertilization level (on individual effect basis), but the impact of their interaction (I × N) was not significant. NC content was the highest in I_3N_3 (114.7 mg/kg) followed by I_3N_3 (106 mg/kg) and lowest in I_1N_1 (57.32 mg/kg). Result of this study clearly indicates that, the deficit irrigation up to a moderate level (15% less the full irrigation level) can markedly improve the lycopene content in the tomato fruit. Similar result was reported by Chen *et al.* (2013). NC content, however, increased with the amounts of irrigation water and N, and was the highest in I_3N_3 at 114.70 mg/kg, which was consistent with the results of Kuscu *et al.* (2014). Result showed that, the more supply of water and nitrogen under drip irrigation along with fertigation technique had

Table 1 Growth parameters of tomato under different treatments

	Plant height (cm)			Number of branches		
	2022	2023	Pooled	2022	2023	Pooled
Interaction (I × N)						
I_1N_1	54	58	56	8	6	7
I_1N_2	71	67	69	10	8	9
I_1N_3	66	60	63	7	7	7
I_2N_1	75	76	75.5	7	9	8
I_2N_2	89	85	87.5	9	9	9
I_2N_3	82	84	83.1	7	7	7
I_3N_1	74	70	72.1	8	4	6
I_3N_2	86	82	84.1	7	7	7
I_3N_3	81	79	80.4	5	7	6
LSD	3.19	2.28	1.76	2.65	1.51	1.58
	ns	ns	ns	ns	s	ns
Irrigation levels						
I_1	63.67	62.67	63.17	8.33	7.00	7.67
I_2	82.00	81.89	81.94	7.67	8.33	8.00
I_3	80.33	78.67	79.50	6.67	6.00	6.33
LSD	2.83	1.05	1.34	1.48	1.07	0.87
	s	s	s	ns	s	s
Nitrogen fertilization levels						
N_1	67.67	68.44	68.06	7.67	6.33	7.00
N_2	82.00	79.33	80.67	8.67	8.00	8.33
N_3	76.33	75.44	75.89	6.33	7.00	6.67
LSD	1.84	1.32	1.02	1.53	0.87	0.91
	s	s	s	s	s	s

Treatment details are given under Materials and Methods.

Table 2 Yield contributing parameters and quality of tomato under different treatments

	Average fruit weight/ plant			Average number of fruits/ plant			Lycopene (µg/g)	NC (mg/kg)	Fruit yield (t/ha)
	2022	2023	Pooled	2022	2023	Pooled	Pooled	Pooled	Pooled
Interaction (I × N)									
I_1N_1	128	125	126.5	15	17	16	20.86	57.32	66.83
I_1N_2	150	146	148	19	16	17.5	33.08	76.45	82.61
I_1N_3	153	147	150	18	14	16	29.48	89.37	76.41
I_2N_1	165	156	160.5	19	16	17.5	25.87	85.51	89.33
I_2N_2	169	175	172	19	17	18	40.42	94.38	100.68
I_2N_3	183	176	179.5	18	16	17	34.87	106.0	96.84
I_3N_1	180	174	177	14	16	15	13.84	87.40	86.61
I_3N_2	193	187	190	17	15	16	17.87	98.89	98.77
I_3N_3	196	190	193	15	16	15.5	22.26	114.70	95.26
LSD	5.05	4.63		2.52	3.17	2.26			
	s	ns	s	ns	ns	ns	s	ns	
Irrigation levels									
I_1	143.67	139.33	141.50	17.33	15.67	16.50	27.77	74.28	75.28
I_2	172.33	169.00	170.19	18.67	16.33	17.50	33.72	95.27	95.62
I_3	189.67	183.67	187.07	15.33	15.67	15.50	18.09	100.03	93.52
LSD	2.18	2.05		2.18	3.32	1.68			
	s	s	s	s	ns	ns	s	s	s
Nitrogen fertilization levels									
N_1	157.67	151.67	154.13	16.00	16.33	16.17	20.19	76.64	80.88
N_2	170.67	169.33	170.27	18.33	16.00	17.17	30.42	89.81	94.02
N_3	177.33	171.00	174.27	17.00	15.33	16.17	28.87	103.53	89.5
LSD	2.91	2.67		1.45	1.83	1.30			
	s	s	s	s	ns	ns	s	s	s

Treatment details are given under Materials and Methods.

highest nitrate content in tomato fruit. Additionally, NC content in this study was well below the national standard (600 mg/kg) recommended by the General Administration of Quality Supervision, Inspection and Quarantine, which indicated that tomatoes produced under this integrated water and nitrogen management approach were acceptable and healthy.

Effect of integrated water and nitrogen management on irrigation water requirement, soil moisture content, irrigation water and nitrogen use efficiency for tomato crop: The total amount of irrigation water was supplied as 301, 256 and 211 mm for irrigation level I_3, I_2 and I_1, respectively. The irrigation water use efficiency (IWUE) was significantly affected by irrigation and nitrogen fertilization levels (on individual or interaction basis). On individual effect basis, the pooled data of soil moisture content (SMC) increased with increase in irrigation water levels but not for nitrogen fertilization levels, SMC first increased with increase in nitrogen level (N_2) and then decrease with further increase in nitrogen dose (N_3). On interaction effect basis, SMC was recorded highest as 27% for the treatment I_2N_2 followed by I_3N_2 and I_3N_2 with a same value of (26%). The lowest SMC was noted under the treatment I_1N_1 with a value of 22%. Result indicates that, the supply of irrigation water at deficit level (I_1 @30% less than full IWR) showed less moisture content in soil which ultimately affected plant growth and fruit yield. The moderate water deficit level (I_2 @15% less than full IWR) result approximately same moisture content in soil as compared to full irrigation level (I_3) which could ultimately support more plant growth, fruit yield and irrigation water use efficiency in tomato cultivation under different water scare regions of Punjab.

IWUE was highest for treatment I_2N_2 (3.93 t/ha-cm) followed by I_1N_2 (3.92 t/ha-cm) and lowest for treatment I_3N_1 (2.88 t/ha-cm). The nitrogen use efficiency (NUE) was significantly affected by irrigation water and nitrogen fertilization levels on individual effect basis but not on interaction effect basis. The NUE increased with increase in water level (I_3) but decreased with increase in nitrogen fertilization levels (N_2 and N_3). NUE was noted highest for treatment I_2N_1 (0.85 t/kg) followed by I_3N_1 (0.82 t/kg). The lowest NUE was noted for treatment I_1N_3 (0.51 t/kg). Hence,

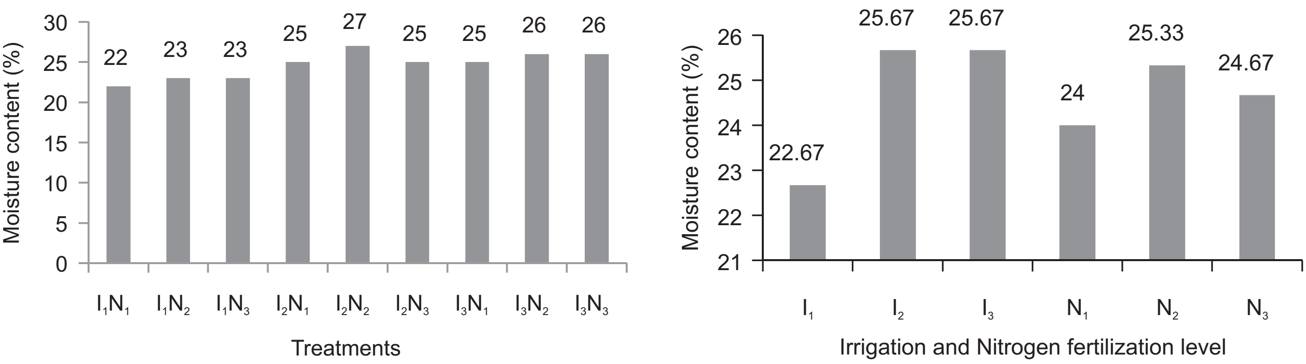

Fig. 1 Soil moisture content (on weight basis) at 10–20 cm depth under different treatments (on interaction basis). Treatment details are given under Materials and Methods.

the selection of optimum water and nitrogen level is very important for improving IWUE and NUE. Previous studies have concluded that both IWUE decrease as the amount of irrigation water increases, because yield decreases for per unit of water. Kuscu *et al.* (2014) indicated that WUE for tomatoes in three levels of nitrogen (N) application was the highest at 0.75 of daily pan evaporation. In the present study, IWUE was highest in I_2 under three nitrogen fertilization levels. In case of irrigation level I_1, the total amount of irrigation water supplied was less than that was in I_2 but it does not support more fruit yield as compared to I_1. Thus, the irrigation levels I_1 and I_3 are not recommended for drip irrigated tomato in selected study area. NUE tends to decrease with increasing rates of nitrogen fertilization (N_2 and N_3) in tomato cultivation. NUE was the lowest in N_3, which was possibly due to the plants' limited N use and sink capacity, resultant in plant saturation. In this study, it was discovered that excessive N application no longer contributed to yield increase and production efficiency, but N instead accumulated in storage organs, which could also be attributed to the lowest NUE in N_3. Sun *et al.* (2013) reported that NUE tended to improve with increasing amounts of irrigation water for a given amount of added N, which is similar to our results.

Table 3 Irrigation water, yield, harvesting index, irrigation water and nitrogen use efficiency under different treatments (on pooled data basis)

	Total irrigation water applied (mm) through drip irrigation	Total nitrogen supplied through fertigation (kg)	Fruit yield (t/ha)	IWUE (t/ha-cm)	NUE (t/kg)	Harvesting index
Interaction (I × N)						
I_1N_1	211	105	66.83	3.17	0.64	0.36
I_1N_2	211	128	82.61	3.92	0.65	0.37
I_1N_3	211	150	76.41	3.62	0.51	0.35
I_2N_1	256	105	89.33	3.49	0.85	0.39
I_2N_2	256	128	100.68	3.93	0.79	0.40
I_2N_3	256	150	96.84	3.78	0.65	0.37
I_3N_1	301	105	86.61	2.88	0.82	0.34
I_3N_2	301	128	98.77	3.28	0.77	0.37
I_3N_3	301	150	95.26	3.16	0.64	0.35
				s	ns	s
Irrigation levels						
I_1	211.00	127.6	75.28	3.57	0.60	0.36
I_2	256.00	127.6	95.62	3.73	0.60	0.39
I_3	301.00	127.6	93.52	3.11	0.74	0.35
			s	s	s	s
Nitrogen fertilization levels						
N_1	256.00	105.00	80.88	3.18	0.70	0.36
N_2	256.00	128.00	94.02	3.71	0.69	0.38
N_3	256.00	150.00	89.5	3.52	0.55	0.36
			s	s	s	s

Treatment details are given under Materials and Methods.

Overall, the tomato had the highest crop yield (100.6 t/ha), IWUE (3.93 t/ha-cm) and NUE when irrigation and nitrogen was administered at 85% of IWR and RDN, respectively. It was might be due to that, the moderate deficit levels of water and nitrogen (which were 15% less than full irrigation and nitrogen requirement) resulted in optimum soil moisture content conditions as well as a balanced increase in vegetative and reproductive components which can be possible factors for more plant growth, fruit yield and irrigation and nitrogen use efficiency. High nitrogen application, on the other hand, can shift the balance in favour of vegetative growth, delaying crop maturity, and diminishing fruit yield of tomato.

Water and nitrogen are the two major inputs in tomato cultivation and their combined effects are more important than the individual effects. In trans-gangetic region of Punjab, the combination of irrigation and nitrogen fertilization level (I_2N_2) was found best which results optimum plant height (87.5 cm), fruit yield (100 t/ha), IWUE (3.93 t/ha-cm), NUE (0.79 t/kg) and good quality tomato fruit. The tomato cultivation under trickle fertigation (with optimum irrigation and nitrogen levels) would be a good strategy to conserve available fresh water resources as well as to minimize the excess use of fertilizers (urea). Overall, it can conclude that, the treatment I_2N_2 (85% of IWR and RDN) will surely enhance growth attributes, yield, water and nitrogen use efficiencies for drip irrigated tomato crop in water scares regions of Punjab. Future studies can be planned to strengthen the results of this research in other regions of India.

REFERENCES

FAOSTAT. 2021. Statistical report by Food and Agriculture Organization of United States.

Chen J L, Kang S Z, Du T S, Qiu R J, Guo P and Chen R Q. 2013. Quantitative response of greenhouse tomato yield and quality to water deficit at different growth stages. *Agricultural Water Management* **129**: 152–62.

Jain N K, Yadav R S and Jat R A. 2021. Drip fertigation influences yield, nutrient uptake and soil properties of peanut (*Arachis hypogaea*). *The Indian Journal of Agricultural Sciences* **91**(2): 258–62.

Javed T, Singhal R K, Shabbir R, Shah A N, Kumar P and Jinger D. 2022. Recent advances in agronomic and physio-molecular approaches for improving nitrogen use efficiency in crop plants. *Frontier in Plant Science* **13**: 877544.

Kiymaz S and Ertek A. 2015. Yield and quality of sugar beet (*Beta vulgaris* L.) at different water and nitrogen levels under the climatic conditions of Kirsehir, Turkey. *Agricultural Water Management* **158**: 156–65.

Kumar J, Patel N, Singh R, Sahoo P K, Sudhishri S, Sehgal V K, Marwaha S and Singh A K. 2021. Development and evaluation of automation system for irrigation scheduling in broccoli (*Brassica oleracea*). *The Indian Journal of Agricultural Sciences* **91**(5): 796–98.

Kuscu H, Turhan A, Ozmen N, Aydinol P and Demir A O. 2014. Optimizing levels of water and nitrogen applied through drip irrigation for yield, quality, and water productivity of processing tomato (*Lycopersicon esculentum* Mill.). *Horticulture Environment and Biotechnology* **55**: 103–14.

Min J, Zhao X, Shi W M, Xing G X and Zhu Z L. 2011. Nitrogen balance and loss in a greenhouse vegetable system in south-eastern China. *Pedosphere* **21**: 464–72.

Sharma V and Singh P K. 2023. Performance of AquaCrop model for predicting yield and biomass of okra (*Abelmoschus esculentus*) crop. *The Indian Journal of Agricultural Sciences* **93**(8): 899–905.

Singhal N, Sharma P, Sharda R, Siag M and Cutting N G. 2021. Assessment of growth parameters and yield of pea (*Pisum sativum*) under different irrigation methods. *The Indian Journal of Agricultural Sciences* **91**(9): 108–11.

Singhal N, Siag M, Sharma P, Sharda R and Singh H. 2022. Impact of moisture regimes on yield and soil microbial population in pea (*Pisum sativum*). *The Indian Journal of Agricultural Sciences* **92**(5): 572–76.

Sun Y, Hu K L, Fan Z B, Wei Y P, Lin S and Wang J G. 2013. Simulating the fate of nitrogen and optimizing water and nitrogen management of greenhouse tomato in north China using the EU-Rotate_N model. *Agricultural Water Management* **128**: 72–84.

Yavuz D, Seymen M, Yavuz N and Tukmen O. 2015. Effects of irrigation interval and quantity on the yield and quality of confectionary pumpkin grown under field conditions. *Agricultural Water Management* **159**: 290–98.