__Original Research Article__

Evaluation of the Effects of Drip Irrigation and Fertigation on Tomato Yield and Water Dynamics under Protected Cultivation

Abstract

The present study was conducted at experimental farm of CSKHPKV, Palampur during with the objectives of evaluating the effects of drip irrigation on soil water behavior and the effects of nutrient schedules on productivity and nutrient uptake at varying drip irrigation levels of tomato under protected condition. The treatments comprised of (a) Three drip irrigation levels; I_1 (Daily drip irrigation @ 2.0 litre/m^2 once in a day during first two months and @ 4.0 litre/m^2 thereafter), I_2 (Daily drip irrigation @ 1.0 litre/m^2 once in a day during first two months and @ 2.0 litre/m^2 thereafter) and I_3 (Daily drip irrigation twice a day with 6 hours interval at @ 1.0 litre/m^2) and (b) Three nutrient schedules viz., NPK_{75} (75% of RDF of which 25% applied as basal and rest 75 % through fertigation at 15 days interval), NPK_{100} (100% of RDF of which 25% applied as basal and 75% through fertigation at weekly interval) and NPK_{150} (150% of RDF of which 25% applied as basal and 75% through fertigation twice a week). The results indicated that the soil water content and soil water stock was higher under I_3 and I_1 and lower under I_2 treatments. However, marketable yield, water use efficiency (WUE) and NPK uptake was significantly higher in I_2 than I_1 and I_3. Among nutrient schedules, marketable yield, WUE and NPK uptake were significantly higher under NPK_{150} nutrient schedule than NPK_{100} and NPK_{75}. The gross return and benefit:cost (B:C) ratio was highest under I_2NPK_{150} followed by I_1NPK_{150} and lowest under I_3NPK_{75}. The study concluded that I_2 and NPK_{150} was most suitable schedule due to higher marketable yield with less water use leading to highest water use efficiency under naturally ventilated polyhouse.

Keywords: Drip irrigation, water productivity, fertigation, soil water stock and water use efficiency

Introduction

With the increasing population and improvement in the dietary habits, the consumption of vegetables has increased. Also, in the present scenario, vegetables play a major role by providing food and nutrition, economic security and more importantly, higher productivity with shorter maturity cycle with greater income leading to improved livelihood [1]. With the increasing population, the demand of vegetables will be 225 million tons by 2020 which will further increase to 350 million tons by 2030 [2]. Vegetable cultivation in Himachal Pradesh has gained significant importance on account of favourable agro-climatic conditions for growing quality off-season vegetables [3]. Low cost naturally-ventilated polyhouses provide a great scope to raise the off-season crop such as tomato for round the year supply [4]. At present, about 137 ha area in Himachal Pradesh has been brought under protected cultivation Greenhouse farming, also known as protected cultivation, is one of the farming systems widely used to provide and maintain a controlled environment suitable for optimum crop production leading to maximum profits [5]. This includes creating an environment suitable for working efficiency as well as for better crop growth [6]. The main advantage of greenhouse farming is that the production can be throughout the year, which is not possible in the open field farming due to heavy rainfall, high temperature and incidence of pest and diseases [6]. Irrigation system is one of the most important components affecting the yield and quality of agricultural produce in greenhouse farming system [4]. Water should be given in proper amount with accurate time application. Therefore, water management is a key to avoid plant moisture stress during the crop growth stages. Several efforts have been made to use irrigation water as efficient as possible under protected cultivation system [7]. The use of drip irrigation saves water and gives better plant yield and quality as it reduces the humidity build up inside greenhouse after irrigation due to precise application of water to the root zone of the crop [4].

Drip (trickle) irrigation offers the potential for precise water management as compared to furrow and sprinkler irrigation [8]. It also provides an opportunity to deliver nutrients in a timely and efficient manner near the root zone (Fertigation). Fertigation is an attractive technology in modern irrigated agriculture which not only increases yield and fertilizer use efficiency but also maintains optimal nutrient levels and water supply according to the specific needs of each crop and soil type [9]. The technique also applies both water and fertilizer at a low rate to the vicinity of plant root zone as per crop needs and according to crop developmental phase, resulting in higher yields and better quality of produce [10]. Further, it can reduce fertilizer usage and minimize groundwater pollution due to fertilizer leaching upon excessive irrigation [11]. Fertigation events can be scheduled as often as irrigation, several times per season. Hence, to obtain the higher crop and water productivity under protected environment, there is a need to regulate drip irrigation frequency based on climatic demand and required fertigation frequency with commonly available water soluble fertilizers such as 19:19:19, 12:61:0, 0:0:50.

Tomato (*Lycopersicon esculentum*) is one of the low-calorie vegetables and is excellent source of antioxidants, dietary fiber, minerals and vitamins [12]. The antioxidants present in tomatoes are scientifically found to be protective of cancers, including colon, prostate, breast, lung, and pancreatic tumors [7]. In greenhouse tomato due to indeterminate nature of crop, vegetative and reproductive stage overlaps and the plant needs nutrients even up to fruit ripening stage for better growth and fruit size, hence, application method such as fertigation may be very effective in greenhouse tomato [13]. Tomato being high value cash crop, having higher nutrient requirements (150:120:60), with 12-15 pickings under protected conditions and with better root proliferation, the plants are likely to behave differently under different soil moisture regimes and fertigation levels. Keeping this in view, the present study was planned to evaluate the effect of drip irrigation and NPK fertigation levels on soil moisture availability, productivity and nutrient uptake of tomato under naturally ventilated polyhouse.

Material and Methods

Study Site

The study was carried out at experimental farm of CSK Himachal Pradesh Krishi Vishvavidyalaya, Palampur, with tomato as a test crop in naturally ventilated polyhouse. The research farm lies in wet temperature zone. The mean air temperature varies from 2°C in January to around 36°C during the months of May-June. The Soil temperature drops as low as 2°C and frost incidences are common. The relative humidity in the region varies from 46 to 84 per cent. The average annual rainfall of the place is about 2500 mm. The soil of the naturally ventilated polyhouse was loam and rich in silt content. The average values of pH and OC of the surface soil (0-15 cm) were 5.67 and organic carbon 12.20 g kg^{-1}. The soil was low in available N (209.01 kg ha^{-1}), high in available P (30.1 kg ha^{-1}) and medium in available K (122.2 kg ha^{-1}).

Treatment details

The experiment comprising of three irrigation and three nutrient schedules. The nine treatment combinations were imposed in a completely randomized design replicated three times. For better establishment of seedlings, drip irrigation was operated daily for 10 minutes for initial 10 days in all the strips and thereafter drip irrigation was operated as per treatment throughout crop growth period. In nutrient schedules, NPK fertilizer doses calculated as per treatment were applied as basal and through fertigation in varying intervals starting from 3rd week of transplanting to 15 days before the final harvest. The details of treatments and detail of fertilizer quantity applied in each treatment are in Table 1 and 2.

Table 1: Details of treatment imposed

Treatment	Details of the treatment
A. Irrigation schedule (I)	
I_1	Daily drip irrigation @ 2.0 litre/m^2 once in a day during first two months and @ 4.0 litre/ m^2 thereafter
I_2	Daily drip irrigation @ 1.0 litre/m^2 once in a day during first two months and @ 2.0 litre/m^2 thereafter
I_3	Daily drip irrigation twice a day with 6 hours interval at @ 1.0 litre/m^2
B. Nutrient schedule (NPK)	
NPK_{75}	75% of RDF of which 25% applied as basal and rest 75% through fertigation at 15 days interval
NPK_{100}	100 % of RDF of which 25% applied as basal and rest 75% through fertigation at weekly interval
NPK_{150}	150 % of RDF of which 25% applied as basal and rest 75% through fertigation twice a week

Table 2: Details of the fertilizer material applied

Treatment	Basal dose (g m^{-2})			Fertigation dose (g m^{-2})/ split			No of splits	Fertigation intervals (days)
	Urea	SSP	MOP	19:19:19	12:61	Urea		
NPK_{75}	9.0	21.0	2.4	13.5	6.3	9.9	8	15
NPK_{100}	12.0	28.0	3.4	8.1	3.6	6.3	16	7
NPK_{150}	18.0	42.0	6.0	9.9	3.6	5.4	32	3

*Top dressing at monthly intervals.

Soil water content and water stock

The changes in soil water content during the season at 0-0.15 m soil depth were determined by thermo gravimetric method periodically during tomato crop growth period. Volumetric water content (ϴ) for different depths was calculated by multiplying the water content (w/w basis) with pre-determined bulk density for that depth [14]. The soil water stock (S) was calculated by multiplying the 'ϴ' values with sampling depth.

Marketable yield and water use efficiency

The tomato fruits were harvested in different pickings. After every picking, the fruits were weighed to obtain the total fruit yield. The yield obtained for each treatment was divided by the quantity of water used for the respective treatments by this method. Water use efficiency was worked out and expressed in kg ha^{-1} mm^{-1} of water used.

$$\text{WUE}\ (\text{g m}^{-2}\text{mm}^{-1}) = \frac{\text{Fruit yield (g m}^{-2})}{\text{Total amount of water used (mm)}} \ldots\ldots\ldots\ldots\ldots (1)$$

Soil sampling and analysis

The initial soil samples were collected before transplanting of the experiment, for analyzing various physico-chemical properties of soil. The available nitrogen was determined by alkaline permanganate method [15], phosphorus by Olsen's method [16] and available potassium in soil was extracted using neutral normal ammonium acetate method.

Economic analysis

The cost of cultivation, net monetary returns and benefit:cost ratio (B:C) were calculated on the basis of prevailing market price of inputs and outputs.

Statistical analysis

The analysis of variance technique (ANOVA) in completely randomized block design was employed to analyze the data statistically by using SAS software, version 9.4 (SAS Institute, Inc., Cary, North Carolina, USA).

Results and Discussion

Soil Water Content and Soil Water Stock

The soil water content (θ) determined at regular interval throughout the growth period is shown in Table 3. The 'θ' determined at early crop growth stages (17 DAT) was 0.38 and 0.38 in I_1, 0.37 and 0.37 m^3 m^{-3} in I_2 and 0.40 and 0.39 m^3 m^{-3} in I_3 at 0-0.15 and 0.15-0.30 m soil depths, respectively. The soil water content at 52 DAT was 0.34 and 0.32 m^3 m^{-3} in I_1, 0.34 and 0.30 m^3 m^{-3} in I_2 and 0.35, 0.37 m^3 m^{-3} in I_3 at 0-0.15 and 0.15-0.30 m soil depth. The soil water content (θ) determined on 81 DAT was 0.38, 0.36 in I_1, 0.37, 0.36 m^3 m^{-3} in I_2, 0.39 and 0.33 in I_3 at 0-0.15 and 0.15-0.30 m soil depths, respectively. The soil water content determined on 106 DAT indicated that the 'θ' values were 0.36, 0.36 m^3 m^{-3} in $I_{1,}$ 0.36, 0.36 m^3 m^{-3} in I_2 and 0.38, 0.32 in I_3 at 0-0.15, 0.15-0.30 m soil depths, respectively. The higher 'θ' in surface layer in I_3 as compared to others may be attributed due to application of water twice a day. Similar results were reported by [4] and [17].

Table 3. Effect of drip irrigation on changes in soil water content and soil water stock (m^3 m^{-3}) during crop growth

Days after transplanting	Soil Water Content		Soil Water Stock	
	Soil depth (m)		Soil depth (m)	
	0-0.15	0.15-0.30	0-0.15	0.15-0.30
	Irrigation level (I_1)			
17 DAT	0.38	0.38	57.6	56.6
52 DAT	0.34	0.32	51.5	48.2
81 DAT	0.38	0.36	57.0	54.0
106 DAT	0.36	0.36	54.0	54.0
	Irrigation level (I_2)			
17 DAT	0.37	0.37	55.6	55.1
52 DAT	0.34	0.30	50.5	44.4
81 DAT	0.37	0.36	55.0	53.7
106 DAT	0.36	0.36	54.3	53.6
	Irrigation level (I_3)			
17 DAT	0.40	0.39	60.7	58.7
52 DAT	0.35	0.37	52.6	55.0
81 DAT	0.39	0.33	58.9	49.6
106 DAT	0.38	0.32	57.7	47.5

The soil water stock (S) calculated for 0-0.15 and 0.15-0.30 m soil depth are given in Table 3. The soil water stock values at 0-0.15 m soil depth were 57.6, 51.5, 57.0 and 54.0 mm in I_1, 55.6, 50.5, 55.0 and 54.3 mm in I_2 and 60.7, 52.6, 58.9 and 57.7 mm in I_3 at 17, 52, 81 and 106 DAT, respectively. The corresponding values of 'S' at 0.15-0.30 m depth were 56.6, 48.2, 54.0 and 54.0 mm in I_1; 55.1, 44.4, 53.7 and 53.6 mm in I_2 and 58.7, 55.0, 49.6 and 47.5 mm in I_3 at 17, 52, 81 and 106 DAT, respectively. The overall results showed that the soil water stock was higher under I_3 and I_1 and lower under I_2 at 17, 52, 81 and 106 DAT at 0-0.15m depth. In I_1 treatments, the soil water stock was higher due to higher quantity of irrigation water applied in comparison to I_2. Similar results were reported by [4] and [18].

Nutrient Uptake

The soil nutrient status at harvest is given from Table 4 to 6. The available nitrogen (N) was higher in I_1 (177.75 kg ha^{-1}) as compared to I_2 and I_3. Under different nutrient schedules, the available nitrogen (N) was statistically higher in NPK_{150} treatment as compared to NPK_{75}, but it statistically at par for with NPK_{100} treatment. The available phosphorus (P) was higher in I_2 (20.96 kg ha^{-1}) irrigation level as compared to other treatments. Under different nutrient schedules, the available phosphorus (P) was significantly higher in NPK_{150} (24.49 kg ha^{-1}) treatment as compared to NPK_{100} (19.46 kg ha^{-1}) and NPK_{75} (15.03 kg ha^{-1}) treatment. The available potassium (K) was significantly higher in irrigation level I_2 (160.78 kg ha^{-1}) as compared to other irrigation levels. Under different nutrient schedules, the available potassium was significantly higher in NPK_{150} (169.24 kg ha^{-1}) as compared to NPK_{100} (143.36 kg ha^{-1}) and NPK_{75} (133.90 kg ha^{-1}) treatment. Similar results were reported by [19], [20], [21] and [22].

Table 4: Effect of drip irrigation and nutrient schedule on available nitrogen

	Drip Irrigation levels			
Nutrient Schedule	**I_1**	**I_2**	**I_3**	**Mean**
NPK_{75}	167.25	156.80	156.80	160.28
NPK_{100}	177.83	188.16	156.80	174.26
NPK_{150}	188.16	188.16	209.07	195.13
Mean	177.75	177.71	174.22	
LSD	**DI**	**NPK**	**Interaction**	
(P=0.05)	NS	27.589	NS	

Table 5: Effect of drip irrigation and nutrient schedule on available phosphorus

Nutrient Schedule	**Drip Irrigation levels**

	I_1	I_2	I_3	Mean
NPK_{75}	16.43	14.63	14.04	15.03
NPK_{100}	18.07	18.67	21.65	19.46
NPK_{150}	21.65	26.43	25.39	24.49
Mean	18.72	20.96	19.91	
LSD	**DI**	**NPK**	**Interaction**	
(P=0.05)	0.959	0.959	1.661	

Table 6: Effect of drip irrigation and nutrient schedule on available potassium

Nutrient Schedule	Drip Irrigation levels			
	I_1	**I_2**	**I_3**	**Mean**
NPK_{75}	129.17	162.03	110.51	133.90
NPK_{100}	141.87	156.05	132.16	143.36
NPK_{150}	168.00	164.27	175.47	169.24
Mean	146.35	160.78	139.38	
LSD	**DI**	**NPK**	**Interaction**	
(P=0.05)	9.914	9.914	17.172	

Marketable yield and water use efficiency

The effect of drip irrigation levels and nutrient schedule on marketable yield of tomato is given in Table 7. The marketable yield was significantly higher in I_2 (6.31 Kg m^{-2}) as compared to I_1 (5.97 Kg m^{-2}) and I_3 (5.88 Kg m^{-2}). The results indicated that the saving of at least 50% of applied water with irrigation level I_2 for attaining the similar marketable yield with I_1. The yield under different nutrient schedule was significantly higher in NPK_{150} (6.53 Kg m^{-2}) as compared to NPK_{100} (5.84 Kg m^{-2}) and NPK_{75} (5.78 Kg m^{-2}) treatment. However, NPK_{75} treatment was statistically similar with NPK_{100} treatment. Similar results were reported by [23], [24], [21], [25], [26], [27] and [13]. The interaction between irrigation levels and nutrient schedule was significant and maximum yield was in I_2NPK_{150} (7.00 kg m^{-2}) and minimum in I_3NPK_{75} (5.63 kg m^{-2}).

Table 7: Effect of drip irrigation and nutrient schedule on marketable yield (kg m^{-2})

Nutrient Schedule	Drip Irrigation levels			
	I_1	**I_2**	**I_3**	**Mean**
NPK_{75}	5.80	5.90	5.63	5.78
NPK_{100}	5.70	6.02	5.80	5.84
NPK_{150}	6.40	7.00	6.20	6.53
Mean	5.97	6.31	5.88	
LSD	**DI**	**NPK**	**Interaction**	
(P=0.05)	0.10	0.10	0.17	

The effect of drip irrigation levels and nutrient schedule on water use efficiency in tomato is given in Table 8. The water use efficiency was significantly higher in I_2 (1.94 g m^{-2} mm^{-1}) as compared to I_1 (1.83 g m^{-2} mm^{-1}) and I_3 (1.86 g m^{-2} mm^{-1}) treatment. Similar results were also reported by Ying et al. [28], Yaghi et al. [29] and Hakim and Chand [30]. The lowest WUE in I_1 was primarily due to higher amount of water used and produced lesser yield in comparison to other drip treatments. Under different nutrient schedules, the water use efficiency was higher in NPK_{150} (1.94 g m^{-2} mm^{-1}) followed by NPK_{100} (1.90 g m^{-2} mm^{-1}) and NPK_{75} (1.79 g m^{-2} mm^{-1}). Similar results were reported by [31] where optimal fertigation was a beneficial practice for improving water use efficiency. Similar results were also reported [22]. The higher WUE in NPK_{150} was primarily due to better root growth and marketable yield. The interaction between irrigation levels and nutrient schedules was significant and maximum water use efficiency was obtained in I_2NPK_{150} (2.12 g m^{-2} mm^{-1}) and minimum was in I_3NPK_{75} (1.76 g m^{-2} mm^{-1}).

Table 8: Effect of drip irrigation and nutrient schedule on water use efficiency (g m^{-2} mm^{-1})

Nutrient Schedule	Drip Irrigation levels			
	I_1	**I_2**	**I_3**	**Mean**
NPK_{75}	1.82	1.78	1.76	1.79
NPK_{100}	1.88	1.91	1.90	1.90
NPK_{150}	1.78	2.12	1.93	1.94
Mean	1.83	1.94	1.86	
LSD	**DI**	**NPK**	**Interaction**	

(P=0.05)	0.079	0.079	0.137

Net returns and economics

The combined effects of drip irrigation levels and nutrient schedules on returns and economics in tomato are given in Table 9. The net return was higher under I_2NPK_{150} (Rs. 230) followed by I_1NPK_{150} (Rs. 206) and lowest under I_3NPK_{75} (Rs. 180). The higher net returns in I_2NPK_{150} and I_1NPK_{150} was due to higher marketable yield. The B:C ratio was highest in I_2NPK_{150} (4.62) and lowest under I_3NPK_{75} (3.97). The higher B:C ratio in I_2NPK_{150} was due to higher yields in comparison to other irrigation levels and nutrient schedules. Similar results were reported by [22] and [32].

Table 9: Effect of drip irrigation and fertigation on returns and B: C ratio

Treatments	Net return (Rs)	B: C ratio
I_1+NPK_{75}	187	4.11
I_1+NPK_{100}	183	4.03
I_1+NPK_{150}	206	4.14
I_2+NPK_{75}	191	4.20
I_2+NPK_{100}	195	4.31
I_2+NPK_{150}	230	4.62
I_3+NPK_{75}	180	3.97
I_3+NPK_{100}	187	4.12
I_3+NPK_{150}	198	3.98

Conclusions

The present study concluded that the irrigation level I_2, consisting of daily drip irrigation at a rate of 1.0 litre/m^2 during the initial two months, followed by a subsequent increase to 2.0 litre/m^2, in combination with NPK_{150} fertilization (150% of RDF), was suitable for cultivation of tomatoes within a naturally ventilated polyhouse in the Himalayan region. This treatment regime exhibited higher marketable yield coupled with reduced water consumption, thereby resulting in higher water use efficiency. The I_2NPK_{150} treatment demonstrated significantly higher net returns and benefit-cost ratio as compared to other treatments. Hence, we recommended for the adoption of daily drip irrigation (I_2) in combination with NPK_{150} fertigation for optimal tomato cultivation under protected conditions in Himalayan region.

References

1. Schreinemachers P, Emmy B, Simmons EB and Wopereis MCS. Tapping the economic and nutritional power of vegetables. Global Food Security. 2018; 16: 36-45.
2. Horticultural statistics at a glance. Department of Agriculture, Corporation and Farmers Welfare. Horticulture Statistics Division. 2020.
3. Chaudhary J and Singh HP. Diversification of Agricultural Crops in Himachal Pradesh: A Shift towards High-Value Crops. International Journal of Current Microbiology and Applied Sciences. 2020; 9(12): 2224-35.
4. Singh J, Sandal SK, Yousuf A and Sandhu PS. Effect of drip irrigation and fertigation on soil water dynamics and the productivity of greenhouse tomatoes. Water. 2020; 15: 2086.
5. Jaswal R and Sandal SK Effect of drip irrigation and NK fertigation on soil water dynamics and water productivity of strawberry under protected conditions. Journal of Soil and Water Conservation. 2022**;** 21(4): 378-384.
6. Rawat S, Bhatt L, Singh PK, Gautam P, Maurya SK, Priyanka, Sabatino L and Kumar P. Combinatorial effect of fertigation rate and scheduling on tomato performance under naturally ventilated polyhouse in Indian humid sub-tropics. Agronomy. 2023; 13: 665
7. Ayenan MAT, Danquah A, Hanson P, Asante IK and Danquah EY. Tomato (*Solanum lycopersicum L.*) Genotypes respond differently to long-term dry and humid heat stress. Horticulturae. 2022; 8: 118.
8. Naik S, Kumar SKS, Rondla SK and Kishan K. Effect of irrigation and N-fertigation levels on broccoli performance in a Polynet house. International Journal of Environment and Climate Change. 2021; 11(12): 261-267.
9. Yue W, Liu L, Chen S, Bai Y. and Li N. Effects of water and nitrogen coupling on growth, yield and quality of greenhouse tomato. Water. 2022; 14: 3665.
10. Sandal SK. and Kapoor R. Fertigation technology for enhancing nutrient use and crop productivity: An overview. Himachal Journal of Agricultural Research. 2015; 41: 114-121.
11. Ankush D, Singh V, Kumar V and Singh DP. Impact of drip irrigation and fertigation scheduling on tomato crop - An overview. Journal of Applied and Natural Science. 2018; 10: 165–170.
12. Costa JM and Heuvelink E. The global tomato industry in tomatoes; CABI Publishing: Wallingford, UK. 2018: 276–313.
13. Mahajan G and Singh K. Response of greenhouse tomato to irrigation and fertigation. Agricultural Water Management. 2006; 84: 202–206.
14. Hillel D. Introduction to Soil Physics. Department of Plant and Soil Science, University of Massachusetts, Amaherst, Massachusetts. 1982; 57-112.
15. Subbiah BV and Asija GL. A rapid procedure for the determination of available nitrogen in soils. Current Science. 1956; 25: 259–260.

16. Olsen SR, Cole CV, Watanabe FS, Dean L.A. Estimation of available phosphorus by extraction with sodium carbonate. United States Department of Agriculture. 1954; 939: 19–33.
17. Kumar J, Kapoor R, Sandal SK, Sharma SK and Saroch K. Effect of drip irrigation and NPK fertigation on soil-plant water, productivity, fertilizer expense efficiency and nutrient uptake of capsicum (*Capsicum annuum L.*) in an acid Alfisol. The Indian Journal of Soil Conservation. 2017; 45: 105–111.
18. Padmaja S, Pasha MDL, Umadevi MS, Hussain A and A Nirmala. Influence of drip irrigation and fertigation on fruit yield and water productivity of cucumber under naturally ventilated polyhouse. International Journal of Environment and Climate Change. 2021; 11(6): 162-168.
19. Guler, Ibriki S and Buyuk. Effects of different nitrogen rates on yield and leaf nutrient contents of drip fertigated and greenhouse grown cucumber. Asian journal of plant Sciences. 2006; 5(4): 657:662.
20. Ahlfos S, Salo T, Pulkkinen T. and Tikanmaki JE. Nutrient demand and uptake by pickling cucumber under drip irrigation in northern climate. Journal of horticultural Science and Biotechnology. 2005; 80(4): 498-502.
21. Amer Kamal H, Midan Sally A and Hatfield Jerry L. Effect of deficit irrigation and fertilization on cucumber. publications from USDA-ARS/UNL Faculty. 2009; 1349
22. Chand ARJ. Nutrient use efficiency and economics of salad cucumber using drip fertigation in naturally ventilated polyhouse. IOSR Journal of Agriculture and Veterinary Science. 2014; 7: 22–25.
23. Abdrabbo MA, Medany A, El-Moniem A and Abou-Hadid EMA. Fertigation management of cucumber plants under plastic houses. Egyptian Journal of Horticulture. 2005; 32(1): 113-15.
24. Guler, Ibriki S and Buyuk. Effects of different nitrogen rates on yield and leaf nutrient contents of drip fertigated and greenhouse grown cucumber. Asian Journal of Plant Sciences. 2006; 5(4): 657:662.
25. Kapoor R, Sandal SK, Sharma SK, Anil and Saroch K. Effect of varying drip irrigation levels and NPK fertigation on soil water dynamics, productivity and water use efficiency of cauliflower (*Brassica oleracea var. Botrytis*) in wet temperate zone of Himachal Pradesh. Indian Journal of Soil Conservation. 2013; 42: 249-254.
26. Feleafel NM, Mirdad MZ and Hassan SA. Effect of NPK fertigation rate and starter fertilizer on the growth and yield of cucumber grown in greenhouse. Journal of Agricultural Science. 2014; 6(9): 8-92.
27. Tekale CD, Tumbare AD, Tekale GS, Danawale NJ and Tambe ST. Effect of different fertigation levels and schedules on growth and yield of cucumber under polyhouse conditions. International Journal of Current Research. 2014; 6: 7353-55.
28. Long YZ, Zhu WM, Lu SJ and Lu M. Effects of different drip-irrigation tubes on tomato (*Lycopersicon esculentum*) cultivation. China Vegetables. 2001; 4-5.

29. Yaghi T, Arslan A and Naoum F. Cucumber (*Cucumis sativus, L.*) water use efficiency (WUE) under plastic mulch and drip irrigation. Agricultural water management. 2013; 128: 149-157.
30. Hakkim AVM and Chand ARJ. Effect of drip irrigation levels on yield of salad cucumber under naturally ventilated polyhouse. IOSR Journal of Engineering. 2014; 4: 18-21.
31. Liang X, Gao Y, Zhang X, Tian Y, Zhang Z. Effect of optimal daily fertigation on migration of water and salt in soil, root growth and fruit yield of cucumber (*Cucumis sativus L.*) in solar-greenhouse. PLoS ONE. 2014; 9(1): 975-85.
32. Patil RV, Bhosale AB and Takte RL. Effect of drip irrigation and fertigation levels on growth and yield of gerbera under greenhouse conditions. Ecology, Environment and Conservation Paper. 2010; 16(2): 235-237.