Original Research Article

Root Growth, Nutrient Uptake and Productivity of Tomato (*Lycopersicum esculentum* Mill.) in Response to Drip Irrigation and Fertigation under Naturally Ventilated Polyhouse condition

Comment [h1]: Solanum lycopersicon is new one

Abstract

The decline in agricultural production and shrinking per capita land holding has resulted in a thrust on vegetable production under protected environment. The efficient management of resources (*i.e.,* water, nutrients etc.) plays an important role in sustainable production. Therefore, the experiment was conducted in naturally ventilated polyhouse at the experimental farm of CSKHPKV, Palampur, Himachal Pardesh with tomato as a test crop during 2018-19. The experiment was laid out incompletely randomized design with 10 treatment combination consist of two drip irrigation levels *viz.,* I_1 (Irrigation was applied from week one to two based on 100% of pan evaporation (Epan), week three to eight based on 40% of Epan, week nine to fourteen based on 60% of Epan, week fifteen to twenty based on 80% of Epan, week twenty one to twenty four based on 100% of Epan) and I_2 (Irrigation was applied based on 100% of Epan during whole the crop period) and five nutrient schedules *viz.,* F_1 (100% recommended dose of fertilizers (RDF) through conventional method, F_2 (100% N through fertigation + PK through conventional method), F_3 (100% NK through fertigation + P through conventional method), F_4 (100% NPK through fertigation) and F_5 (50% NPK through conventional method + 150% NPK through fertigation) replicated thrice. The results highlighted that the root length (316.53 cm), fruit yield (7.33 kg/m^2) and net returns (Rs. 173.12) were significantly higher under I_2 treatment as compared to I_1treatment. Among the nutrient schedules, root growth parameters, NPK uptake, fruit yield (7.62 kg/m^2) and net returns (Rs. 177.80) were significantly higher under F_5 treatment. However, the benefit:cost (B:C) ratio (3.75) was significantly higher under F_4 treatment. The irrigation level I_2 with fertigation treatment F_4 (100% NPK through fertigation) performed better among all the treatment combinations and should be recommended for higher tomato production under naturally ventilated polyhouse in northwestern Himalayan region.

Comment [h2]: Very old data

Keywords: **Tomato, nutrient uptake, fertigation, nutrient scheduling and fruit yield**

Introduction

In India, vegetable production gained significant importance for increasing the income of small and marginal farmers. The vegetable growers require new technologies for greater crop production without compromising quality [1].Among the vegetables, tomatoes (*Lycopersicum esculentum*)stand as one of the most widely cultivated and consumed vegetable [2].It is second most important crop next to potato that grown throughout the world [3]. Tomato has become a staple ingredient in numerous cuisines throughout the world. Tomato is also considered as

Comment [h3]: It's a old name Solanum lycopersicon is new one important dietary and commercial vegetable cropbeyond its culinary benefits [4]. It serve as a cornerstone of nutritious diets due to rich source of essential minerals like P, Ca, Fe, vitamins and antioxidants (mainly lycopene and β-carotene)[5].The lycopene is main antioxidant that is found in tomato which prevents from development of many form of cancer and improves immune system.

Comment [h4]: Minimize the words and write good sentence

The cultivation of tomato under protected conditions increased rapidly due to decrease in cultivable land and water resources.Protected cultivation gained significant importance due to higher yields with better quality[6]. This technique is suitable for year round cultivation of tomatoes which increases the income of farmers. Protected cultivation is highly efficient in use of water and nutrients due to decrease in evaporation and use of advanced technologies such as drip irrigation and fertigation[7]. The irrigation and nutrient management are important aspect in vegetable production for higher crop productivity with better quality because higher amount of water and fertilizers are required in vegetable production. Drip irrigation is one of most efficient method of irrigation in vegetable production[8]. The delivery of low amount of water with higher frequency reduces the water losses (evaporation, drainage) with concomitant increasein the water use efficiency[9].The drip irrigation helps to maintain optimum soil moisture conditions in root zone, which increase the uptake of nutrients[10]. Fertigation, application of fertilizers along with irrigation, is one of the most effective methods of supplying the nutrients according to the requirements of crop and helps to maintain the soil fertility besides increasing the quality of the produce[11]. It helps to increase the availability of nutrients in plant root zone by reducing the leaching losses[12].Drip irrigation combined with optimum fertilizers helps in supply of timely and adequate amount of irrigation and nutrient application[13].The challenge for agriculture production over the coming decades will be the use ofresources in a sustainable way. The sustainability of any system requires optimal utilization of resources such as water, fertilizer and soil. Keeping the above mentioned facts in view, the present study was conducted to determine the effect of drip irrigation and fertigation on root growth, nutrient uptake and productivity of tomatoes in order to find out the most suitable drip irrigation and fertigation level for tomato under naturally ventilated polyhouse.

Comment [h5]: Precise the content in to 5-6 sentences. Write in 2 paragraphs

Materials and Methods

Study site

The study was conducted at the experimental farm of CSKHPKV, Palampur, with tomato as a test crop in a polyhouse having natural ventilation. The polyhouse dimensions were 15 m length and 7 m wide and it was covered with plastic sheet. The experimental site is situated at 32° 36’ 0” N and 76° 17’ 60” E, having altitude 1290 m above mean sea level (msl). The climate of the experimental site was sub-humid with minimum and maximum temperature of 2℃ and 36℃, with their plateau in January and June, respectively. The mean yearly rainfall was around 2500 mm with relative humidity ranging from 46 to 84%. The soil characteristics of study area were determined at the commencement of the experiment. The initial soil properties of study area are given in Table 1.

Table 1. Selected properties of experimental soil

Soil attributes	Values
Textural class	Loam
Sand (%)	38
Silt (%)	42
Clay (%)	20
Particle density (Mg/m^3)	2.31
Bulk density (Mg/m^3)	1.22
Water holding capacity (%)	56.78
Porosity (%)	47.19
Saturated hydraulic conductivity (x 10^{-6} m/s)	1.47
Infiltration rate (m/s)	2.75 x 10^{-5}
Mean weight diameter (mm)	0.92
Electrical Conductivity (dS/m)	0.26
pH	5.69
Organic carbon (g/kg)	12.60
Available N (kg/ha)	165.6
Available P (kg/ha)	19.7
Available K (kg/ha)	218.8

Comment [h6]: Use multiplication symbol

Treatment details

The experiment was carried out in factorial (irrigation levels and nutrient schedules) completely randomized design with three replications. The first factor was drip irrigation with two levels, whereas second one was nutrient schedule with five nutrient schedules. The treatment details are presented in Table 2. The seed of tomato hybrid (PTH-1) was sown in media of cocopeat, vermiculite and perlite in 1:1:2 ratio. After 30 days, seedlings with 3-4 leaves and 8-10 cm height were manually transplanted in the month of April 2018 and harvested in last week of August, 2018. The gravity fed drip irrigation system with sixteen meter long main line connected with fifteen laterals spaced forty five cm apart were used for irrigation and fertigation. Each lateral was three m long with eight inline drippers spaced thirty cm apart and total 30 strips were raised each of 1.5 m^2 size. The mean discharge rate of each dripper was 0.60 l/h and the discharge uniformity was about 90%. The irrigation water was applied on the basis of average Epan. The field layoutis shown in figure 1.

Table 2. Treatment details of the experiment

Treatments	**Details of the treatment**
A. Irrigation schedule	

I_1	Irrigation was applied from week one to two based on 100% of Epan, week three to eight based on 40% ofEpan, week nine to fourteen based on 60% of Epan, week fifteen to twenty based on 80% of Epan, week twenty one to twenty four based on 100% of Epan
I_2	Irrigation applied based on 100% of Epan from week one to till harvest
B. Nutrient schedule	
F_1	100% RDF through conventional method
F_2	100% N through fertigation + 100% P and K through conventional method
F_3	100% NK through fertigation + 100% P through conventional method
F_4	100% NPK through fertigation
F_5	150% NPK through fertigation + 50% NPK through conventional method

The recommended dose of fertilizers (100% RDF) was 150 kg N, 120 kg P and 60 kg K per hectare. In nutrient schedule, fertigation was started from 3rd week after transplanting and fertilizer doses were calculated as per the treatment. The water-soluble fertilizers such as urea, potassium sulphate and mono-ammonium phosphate were used for fertigation. The fertilizers were mixed in the fertigation tank having 30 litres capacity and conveyed to main line by using ventury with irrigation system. In conventional method, half of the N and full doses of P and K were given as basal and the remaining half of N was top dressed after one month of transplanting.

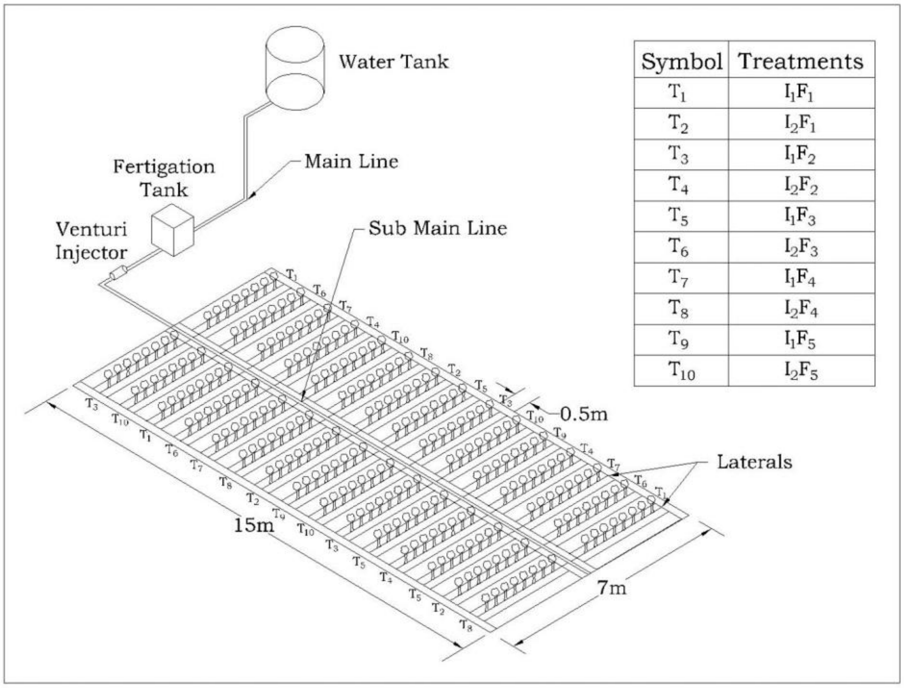

Figure 1. Layout of field with drip system

Root growth parameters

The influence of drip irrigation and nutrient schedule on root growth was measured by different root growth characteristics (*i.e.* root length, root volume, root mass and specific root length) at harvesting. The root samples were collected by selecting five plants from each plot. The root length was calculated by modified version of Newman formula [14] that is given below

$$\text{Root length (cm)} = \frac{11}{14} \times \text{number of intersections (N)} \times \text{ grid unit} \qquad (2)$$

The root volume was measured by volume-displacement method [15]. The roots were then dried in an oven at 65°C until weight remained constant. The specific root length was computed by dividing the root length over dry weight of roots [16].

Plant sampling and analysis

Plant samples were collected randomly from all the plots at harvest and oven dried at 65 °C till constant weight remained constant. The samples were ground in a willey mill and preserved in butter paper bags and treatment-wise labeled for analysis. For estimating nitrogen content, the samples were dried, ground and digestedin di-acid mixture (H_2SO_4:$HClO_4$) and analyzed for nutrient content by colorimetric method [17] and Nuptake was calculated by using following formula .

$$\text{N uptake } (g/m^2) = \frac{\text{N content } \times \text{ Dry matter production}}{100} \quad (5)$$

Thephosphorus (P) content was estimated by vanadomolybdophosphoric yellow color method[18] and P uptake by plants was calculated by following formula that given below:

$$\text{P uptake } (g/m^2) = \frac{\text{P content } \times \text{ Dry matter production}}{100} \quad (6)$$

The flame photometer method [19] was used for determination of potassium (K) content. The K uptake by plants was calculated by using following formula:

$$\text{K uptake } (g/m^2) = \frac{\text{K content } \times \text{ Dry matter production}}{100} \quad (7)$$

Fruit yield and net returns

The tomato fruit matured after 50 days of pollination. After every picking, the fruits were weighed and total yield was calculated by the sum of fruit weight obtained at every picking per plot.The economic feasibility of employing various drip irrigation and fertigation levels in crop was assessed through calculation of cost of cultivation, net returns and benefit cost (B:C) ratio. Cost of cultivation, netmonetary returns and B:C ratio were calculated on thebasis of prevailing market price of inputs and outputs.Net returns for various treatments were calculated by the subtracting the total input cost from gross returns of each respective treatment. The B:C ratio for each treatment was computed by dividing the net returns by the cost of cultivation associated with that specific treatment.

Statistical Analysis

The data analysis was conducted by using two-way analysis of variance (ANOVA) method, utilizing the statistical software SAS 9.1. The Duncan's multiple range test was used for comparison of treatments mean effects, with a predetermined significance level of ($P \leq 0.05$).

Results and Discussion

Root growth parameters

The effects of drip irrigation levels and nutrient schedules on root growth parameters at harvest are given in Table 3. The data revealed that the root length was significantly higher in I_2 (316.53 cm) as compared to I_1 (295.47 cm),whereas, the root dry weight, root volume and specific root length were non-significant for various drip irrigation levels. The total root length was more in drip irrigated crops as compared to surface irrigated crop [20]. It may be ascribed to adequate supply of moisture which helps in better proliferation of roots. The drip irrigation maintains the availability of moisture that directly helps in better root spread and development of fibrous root system thereby enhancingcrop nutrient uptake [21].Among different nutrient schedules, the root length was significantly higher in F_5 (491.67 cm) and lower in F_1 (134.50 cm) treatment as compared to other treatments. The root volume was higher under F_3 (22.83 cm^3) and lower in F_1 (13.83 cm^3) than all other treatments. The root weight was significantly higher under F_5 (6.03 g) as compared to other treatments and significantly lower in F_1 (2.86 g) treatment. The specific root length was significantly higher under F_3 (101.36 cm/g) as compared to F_2 (75.24 cm/g) and F_1 (50.62 cm/g) but was statistically similar with F_4 (85.55 cm/g) and F_5 (81.54 cm/g).

The F_5 treatment enhanced the availability of nutrients which resulted in better root growth and split fertigation of phosphorus at regular interval assisted the crops to absorb more P throughout the crop growth period and minimized nutrient losses. However, in conventional method P was applied as basal dose that resulted in substantial P fixation in the soil thereby decreasing the availability forroots and eventually reduces the growth and development of roots of the crops. Similar results were reported by Debbarma et al. [21] and Jeelani et al. [22]. The root growth was increased with increase in drip irrigation and fertigation levels due to consistent supply of water and nutrients in the root zone which enhanced the nutrient availability throughout the crop growth period and results in better root growth and development. The results were concurrent with the findings of Kumar et al. [23] and Jeelani et al. [22]. The higher root volume and specific root length in F_3 may due to application of phosphorus as basal dose which might have contributed to better root volume and specific root length. Similar results were reported by Machado et al.[24] and Debbarma et al. [21].

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Table 3. Effect of drip irrigation and nutrient schedules on root growth parameters

Treatments	Root Length (cm)	Root Volume (cm^3)	Root Weight (g)	Specific Root length (cm/g)
Irrigation (I)				
I_1	295.47^{B}	19.80^{A}	3.83^{A}	75.85^{A}
I_2	316.53^{A}	20.80^{A}	3.87^{A}	81.87^{A}
Fertigation (F)				
F_1	173.50^{c}	134.50^{d}	13.83^{b}	2.86^{d}
F_2	179.50^{bc}	234.00^{c}	22.67^{a}	3.11^{cd}
F_3	181.17^{bc}	327.67^{b}	22.83^{a}	3.25^{c}
F_4	186.17^{b}	342.17^{b}	19.67^{a}	4.00^{b}
F_5	199.17^{a}	491.67^{a}	22.50^{a}	6.03^{a}
Interaction (I×F)	NS	NS	NS	NS

Different letters in columns represent significant difference at $p \leq 0.05$ level of probability: NS denotes non-significant.

Nutrient Uptake

The nutrient uptake by tomatoes was significantly affected by various levels of drip irrigation and nutrients schedule (table 4). The nitrogen uptake determined in fruit and straw was non-significant under the different irrigation levels. Among different nutrient schedules, significantly higher nitrogen uptake in fruit was recorded under F_4 (18.24 g/m^2) and F_5 (17.96 g/m^2) as compared to F_1 (13.33 g/m^2) but was statistically similar with F_2 (15.17 g/m^2) and F_3 (15.16 g/m^2).In case of straw, the nitrogen uptake was significantly higher under F_2 (2.68 g/m^2) and F_3 (2.63 g/m^2) as compared to F_1 (2.13 g/m^2) and F_4 (2.03 g/m^2) but was statistically similar with F_5 (2.54 g/m^2). The N accumulation in fruit was increased with increase in fertigation rate as compared to conventional method because F_5 treatment provided the adequate amount of nitrogen during vegetative growth which resulted in better growth and development. The high fertigation rate also helps in luxury consumption of N at later stages. The higher accumulation of N may not be important for plant growth but helps in increasing the uptake efficiency of N during growth period. Similar results were reported by Hu et al. [25] and Farneselli a et al. [26]. In, straw, the N uptake recorded under F_2 was significantly higher because fertigation of 100% N provides nutrient in optimum amount at right time that helps in better growth of plants. The fertigation maintains the availability of nitrogen upto later stages and directly plays important role in N uptake efficiency of plants. The results were concurrent with the findings of Feng et al. [27], Farnesellia et al. [26] and Kiruthiga et al.[13].

The phosphorus uptake was non-significant under different irrigation levels in fruit and straw. Among different nutrient schedules, the phosphorus uptake in fruit was significantly higher under F_5 (2.56 g/m^2) as compared to F_3 (2.36 g/m^2), F_2 (2.10 g/m^2) and F_1(1.98 g/m^2) but was statistically similar with F_4 (2.47 g/m^2). In straw, significantly higher phosphorus uptake was recorded under F_4 (0.20 g/m^2) as compared to F_3 (0.18 g/m^2) and F_1 (0.17 g/m^2) but was statistically similar with F_5 (0.19 g/m^2) and F_2 (0.18 g/m^2). The interaction between irrigation levels and nutrient schedules was significant for phosphorus uptake in straw and non-significant in fruit.The phosphorus accumulation recorded in fruits under F_5 was significantly higher because higher fertigation rate helps to meet up the P requirement of plants at different growth stages and maintains the availability of P throughout the growth period. The P demand of plants was increased by almost 50 percent under fertigation. Similar results were reported by Farnesellia et al. [26] and Castellanos et al. [28], So the higher rate of fertigation helps to maintain the optimum concentration of P and provides the better growth and uptake by plants. The P accumulation in straw was significantly higher under the 100% NPK fertigation because fertigation reduces the nutrient losses and increases the nutrient use efficiency of plants. Similar results were reported by Yaghi et al. [29] and Wang and Xing [30].

The potassium uptake in fruit and straw was non-significant under different irrigation levels. Among different nutrient schedules, significantly higher potassium uptake in fruit was recorded under F_5 (10.79 g/m^2) as compared to F_3 (9.37 g/m^2), F_2 (9.24 g/m^2) and F_1 (7.89 g/m^2) but was statistically similar with F_4 (10.35 g/m^2). In straw, significantly higher potassium uptake was recorded under F_3 (2.38 g/m^2) as compared to F_4 (2.23 g/m^2), F_1 (2.13 g/m^2) and F_2 (2.08 g/m^2) but was statistically similar with F_5 (2.31 g/m^2). The accumulation of potassium in fruit (K) under F_5 treatment was significantly higher and in straw K accumulation was significantly higher under F_3 treatment because tomatoes are strong sinks for K and stored more K as compared to sources. The interaction between irrigation levels and nutrient schedules was non-significant. Similar results were reported by Gupta et al. [31].

Table 4. Effect of drip irrigation and nutrient schedules on nutrient uptake (g/m^2)

Treatments	**N Uptake (g/m^2)**			**P Uptake (g/m^2)**			**K Uptake (g/m^2)**		
	Fruit	Straw	Total	Fruit	Straw	Total	Fruit	Straw	Total
Irrigation (I)									
I_1	15.65^A	2.36^A	18.00	2.37^A	0.18^A	2.55	9.42^A	2.19^A	11.59
I_2	16.30^A	2.44^A	18.81	2.23^A	0.18^A	2.41	9.64^A	2.26^A	11.91
Fertigation (F)									
F_1	13.33^b	2.13^{bc}	15.46	1.98^c	0.17^b	2.15	7.89^c	2.13^{bc}	10.02
F_2	15.17^{ab}	2.68^a	17.85	2.10^{bc}	0.18^{ab}	2.28	9.24^{bc}	2.08^c	11.32

F_3	15.16^{ab}	2.63^{a}	17.79	$2.36a^{bc}$	0.18^{b}	2.56	9.37^{b}	2.38^{a}	11.75
F_4	18.24^{a}	2.03^{c}	20.44	2.47^{ab}	0.20^{a}	2.67	10.35^{ab}	2.23^{abc}	12.61
F_5	17.96^{a}	2.54^{ab}	20.49	2.56^{a}	0.19^{ab}	2.75	10.79^{a}	2.31^{ab}	13.05
Interaction (I×F)	NS	NS	NS	NS	0.03	NS	NS	NS	NS

Different letters in columns represent significant difference at $p \leq 0.05$ level of probability: NS denotes non-significant.

Fruit yield and Economic returns

The data (Table 5) showed that fruit yield was significantly influenced by different irrigation and fertigation schedules. The fruit yield recorded under I_2 was significantly higher as compared to I_1. The higher fruit yield in I_2 may be due to increased water application which promotes plant growth improves nutrient uptake and eventually increased yield. Among different nutrients schedule, the fruit yield was significantly higher under F_5 and F_3 than F_1 but was statistically similar with F_2 and F_4 treatments. The higher marketable fruit yield under F_5 due to higher fertilizer application rate led to better plant growth and development which resulted in produced maximum yield. Similar results were reported by Alordzinu et al.[32] and Jaswal and Sandal [33]. The interaction between irrigation levels and nutrient schedule was non-significant. The higher marketable fruit yield under F_5 due to increase in fertilizers application might have resulted in higher nutrient availability which improved growth and development and ultimately leading to higher yield. There was substantial increase in total fruits per plant, mean fruit weight per plant and overall yield with the increased application of NPK fertilizer. The F_5 treatment demonstrated significantly higher fruit yield as compared to other treatments, potentially indicating a more favorable response of plants to increased fertilizer application. The maximum yield can be achieved by minimizing moisture stress on tomato plants. However, the application of irrigation water exhibited a positive correlation with relative increase in total marketable yield. Similar results were reported by Alordzinu *et al*. [32].

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The data showed that net returns and B:C ratio was significantly affected by different drip irrigation and nutrient schedules (Table 5). The net returns and B:C ratio recorded under I_2 was significantly higher as compared to I_1. These results can be attributed to the fact that the I_2 treatment resulted in greater marketable yield, consequently increasing both net returns and the B:C ratio. Among different nutrient schedule, the net returns was significantly higher in F_5 than F_1 treatment but was statistically similar with F_3 and F_4 treatments. The B:C ratio was significantly higher in F_4 and lower in F_1. The treatments with 100% recommended dose of fertilizer have maximum B:C ratio (3.75). The significantly higher B:C ratio in F_4 can attributed to its higher yield at lower cost of inputs, compared to other treatments because B:C ratio directly depends on total yield and cost of cultivation of crop, The interaction between irrigation levels and nutrient schedules was non-significant. Similar results were reported by Rawat *et al*. [34], Kushwaha *et al*. [35] and Kumar *et al*. [36].

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Table 5. Effect of drip irrigation and nutrient schemes on fruit yield and economic return variables

Treatments	Fruit yield (kg/m^2)	Net returns (Rs.)	B:C ratio
Irrigation (I)			
I_1	6.97^B	162.14^B	3.45^B
I_2	7.33^A	173.12^A	3.69^A
Fertigation (F)			
F_1	6.38^b	146.52^c	3.26^c
F_2	7.09^{ab}	166.34^b	3.60^b
F_3	7.34^a	173.94^{ab}	3.68^b
F_4	7.33^{ab}	173.56^{ab}	3.75^a
F_5	7.62^a	177.80^a	3.49^b
Interaction (I×F)	NS	NS	NS

Different letters in columns represent significant difference at $p \leq 0.05$ level of probability: NS denotes non-significant.

Conclusion

The application of drip irrigation on the basis of 100% of Epan was the most suitable treatment with higher root length (316.53 cm) with higher nutrient uptake leading to higher crop yield with higher net returns and B:C ratio. Among nutrient schedule, the application of 100% RDF through fertigation was the most suitable fertigation level as compared to other treatments as it resulted in better root growth, nutrient uptake and higher yield. The B:C ratio was significantly higher under F_4 treatment. Therefore, irrigation based on 100% of Epan and 100% RDF through fertigation should be recommended for cultivation of tomato under naturally ventilated polyhouse in Himalayan region.

References

1. 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.
2. Costa JM.,Heuvelink E. The global tomato industry in tomatoes; CABI Publishing: Wallingford, UK.2018: 276–313.
3. Dagade SB, Dhaduk LK, Hariprasanna K, Mehata DR, Bhatt VM and Barad AV. Parent offspring relations of nutritional quality traits in 8 × 8 partial diallel cross of fresh tomatoes. International Journal of Applied Biology and Pharmaceutical Technology. 2015; 6: 45–55.
4. Mehriya ML, Geat N, Singh SH, Mohamed A Mattar MA and Elansary H. Response of drip irrigation and fertigation on cumin yield, quality and water use efficiency grown under arid climatic conditions. Agronomy. 2020; 10: 1711.

5. Ayenan MAT, Danquah A, Hanson P, Asante IK andDanquah EY. Tomato (Solanum lycopersicum L.) Genotypes respond differently to long-term dry and humid heat stress. Horticulturae. 2022; 8: 118.
6. Naik S, Kumar SKS, RondlaSK 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.
7. 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.
8. Ankush D, Singh V, Kumar V and SinghDP. Impact of drip irrigation and fertigation scheduling on tomato crop-An overview. Journal of Applied and Natural Science.2018; 10: 165–170.
9. Sathyamoorthy NK, Krishnasamy S, Swaminathan C, Prabhakaran J, Ramanathan SP, Anbarasu M,SenthilrajaK and Guhan V. Evaluating the irrigation regimes and fertigation schedule of red gram (Co (Rg)-7) under drip irrigation system. International Journal of Environment and Climate Change. 2022; 12(10): 1330-1336.
10. Elzopy KA, Biradar MS, Channal HT, Manjunath MV, Palled YB, Radder BM and Patil PL. NPK uptake of tomato as influenced by irrigation regimes and fertigation levels under greenhouse condition. Asian Journal of Advances in Agricultural Research. 2017; 3(1): 1-10.
11. Malam KV, Solanki RM. Growth, yield and water use efficiency of sweet sorghum [Sorghum bicolor (L.) Moench] affected by drip irrigation and nitrogen levels through fertigation. International Journal of Environment and Climate Change. 2022; 12(11): 2407-2424.
12. Suresh G, Sudhakara Babu SN, Qureshi AA andRamulu V. Growth, productivity, economics, and water use efficiency of rabi castor (Ricinus communis) as influenced by drip fertigation. International Journal of Environment and Climate Change. 2022; 12(9): 157-167.
13. Kiruthiga B, Kumar KA, Kumar KS and Srinivas A. Dry matter production and nutrient uptake of coloured capsicum hybrids (Capsicum annuum var. grossum L. L.) as influenced by different irrigation levels under shade net. International Journal of Environment and Climate Change.2021; 11(9): 1-8,
14. Marsh BB. Measurement of length in random arrangement of lines. Journal of Applied Ecology. 1971; 8: 265-267.
15. Birouste M, Ledezma EZ, Bossard C, Perez-Ramos IM and Roumet C. Measurement of fine root tissue density: a comparison of three methods reveals the potential of root dry matter content. Plant and Soil. 2014**;** 374: 299–313.
16. Tenant D. A test of a modified line intersection method of estimating root length. Journal of Applied Ecology J. Ecol. 1975; 63: 995-1001.

17. Lindner RC. Rapid analytical method for some of the more common inorganic constituents of plant tissues. Plant Physiology. 1944; 19(1): 76-89.
18. Koenig CN and Johnson C. Colorimetric determination of phosphorus in biological materials. Industrial and Engineering Chemistry. 1942; 14(2): 155-56.
19. Rowell DL. Soil Science: Methods and Applications Harlow: Longman Scientific & Technical. 1944.
20. Mahajan G, SinghK. Response of greenhouse tomato to irrigation and fertigation. Agricultural Water Management. 2006; 84: 202–206.
21. Debbarma S, Bhatt L, Raghav M and Lavlesh. Influence of drip fertigation levels and scheduling on root characters of broccoli (Brassica oleracea L var. italic). International Journal of Chemical Studies.2019; 5: 746-751.
22. Jeelani J, Katoch KK, Sandal SK and Gupta RK. Effect of varying drip irrigation levels and different methods of NPK fertilizer application on soil water dynamics, water use efficiency and yield of broccoli (Brassica oleracea L. var. italica) in wet temperate zone of Himachal Pradesh. Indian Journal of Pure & Applied Biosciences. 2017; 5: 210-220.
23. 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 (*Capsicumannuum L.*) in an acid Alfisol. The Indian Journal of Soil Conservation. 2017; 45: 105–111.
24. Machado RM, Rosario MD and Oliveira G. Tomato root distribution, yield and fruit quality under subsurface drip irrigation. Plant and Soil. 2003; 255: 333–341.
25. Hu J, Gettel G, Fan Z, Lv H, Zhao Y, Yu Y, Wang J, Bahl KB, Li G and Lin S. Drip fertigation promotes water and nitrogen use efficiency and yield stability through improved root growth for tomatoes in plastic greenhouse production. Agriculture, Ecosystems & Environment.2021; 313: 107379.
26. Farnesellia M, Benincasaa P, Tostia G, Simonneb E, Guiduccia M and Tei F. High fertigation frequency improves nitrogen uptake and cropperformance in processing tomato grown with high nitrogen and water supply. Agricultural Water Management.2015; 154: 52–58.
27. Feng XY, Jing-Xuan PU, Hai-Jun L, Dan W, Yu-Hang L, Shu-Ting Q, Tao L and Hao RL. Effect of fertigation frequency on soil nitrogen distribution and tomato yield under alternate partial root-zone drip irrigation. Journal of Integrative Agriculture. 2023; 22: 897–907.
28. Castellanos JZ, Ojodeagua JL, Mendez F, Villalobos-Reyes S, Badillo V, Vargas P, FerratLI. Phosphorus requirements by garlic under fertigation. Better Crops International. 2001**;** 15: 21-23.
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. Wang X, Xing Y. Evaluation of the effects of irrigation and fertilization on tomato fruit yield and quality: a principal component analysis. Scientific. Reports. 2017; 7: 350.
31. Gupta AJ, Chattoo MA and Singh L. Drip irrigation and fertigation technology for improved yield, quality, water and fertilizer use efficiency in hybrid tomato. Journal of Agricultural Research. 2015; 2: 94-99.
32. Alordzinu KE, Appiah SA, Aasmi AA, Darko RO, Li J, Lan Y, Adjibolosoo D, Lian C, Wang H and Qiao S. Evaluating the influence of deficit irrigation on fruit yield and quality indices of tomatoes grown in sandy loam and silty loam soils. Water. 2022; 14: 1753.
33. 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.
34. 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.
35. Kushwaha RK, Sharma NP, Baldodiya VK. Profitability of tomato (Lycopersicon esculentum) production in some selected Areas in Panna District of Madhya Pradesh. International Journal of Current Microbiology and Applied Sciences. 2018; 6: 2117-24.
36. Kumar PS, Choudhary VK, and Bhagawati R. Influence of mulching and irrigation level on water use efficiency, plant growth and quality of strawberry (Fragaria×ananassa). Indian Journal of AgriculturalSciences. 2012;82: 127-33.

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