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Evaluation of the Effects of Drip Irrigation and Fertigation scheduling on Tomato Yield under Polyhouse

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

In Northwestern Himalayas, there is scarcity of water owing to rugged terrain which results in lower tomato yield. Therefore to enhance the productivity of tomato, the experiment was conducted to evaluate the effects of drip irrigation and nutrient schedules on soil water dynamics and productivity of tomato under polyhouse. The treatments consisted of three drip irrigation levels viz., 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 three nutrient schedules viz., NPK_{75} (75% of RDF, 25% applied as basal and 75% through fertigation at 15 days interval), NPK_{100} (100% of RDF, 25% applied as basal and 75% through fertigation at 7 days interval) and NPK_{150} (150% of RDF, 25% applied as basal and 75% through fertigation twice a week). The results showed that the soil moisture content and soil water stock was higher under I_3 and I_1 and lower under I_2 treatments. The marketable yield (6.31 kg m^{-2}), water use efficiency (WUE) (1.94 g m^{-2} mm-

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^{1}) and NPK uptake was significantly higher in I_2 than I_1 and I_3. Among nutrient schedules, marketable yield (6.53 kg m^{-2}), WUE (1.94 g m^{-2} mm^{-1}) and NPK uptake were significantly higher under NPK_{150} nutrient schedule than NPK_{100} and NPK_{75}. The net returns (Rs. 230) and benefit:cost (B:C) (4.62) ratio was highest under I_2NPK_{150} followed by I_1NPK_{150} and lowest under I_3NPK_{75}. The study concluded that 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 NPK_{150} (150% of RDF, 25% applied as basal and 75% through fertigation twice a week) was most remunerative combination due to higher marketable yield and water use efficiency under polyhouse.

Keywords: Drip irrigation; water productivity; fertigation; tomato.

1. INTRODUCTION

With the increasing population and improvement in the dietary habits, the consumption of vegetables has increased. Also, in the present scenario, vegetables plays a major role by providing food and nutrition and economic stability with higher productivity in shorter maturity cycle and greater income leading to improved livelihood [1]. The projected demand of vegetables will be 290 million tons by 2025 which will further increase to 350 million tons by 2030 [2]. Vegetable cultivation in Himachal Pradesh has gained significant importance owing to favourable agro-climatic conditions for growing off-season vegetables with better quality [3]. Low cost naturally-ventilated polyhouses provide a great scope in cultivation of the off-season crop such as tomato for year round 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 maintain a controlled environment which is suitable for optimum crop production leading to maximum profits [5] and [6]. The main advantage of protected cultivation is that the crops can be grown throughout the year, which is not possible in the open field cultivation due to heavy rainfall, high temperature and incidence of pest and diseases [6]. Irrigation is one of the most important factor that affects the yield and quality of the produce [4]. Water should be applied at accurate time and in proper amount. Therefore, the efficient management of water is a key to maintain optimum yield with favourable soil moisture conditions by avoiding plant moisture stress during critical crop growth stages. Several methods have been made to use irrigation water as efficient as possible under protected cultivation [7]. The utilization of drip irrigation methodology offers a dual advantage by conserving water resources while simultaneously enhancing crop productivity and quality. This efficacy is attributed to precise application of water directly to the root zone of plants. It not only minimizes the humidity but also provides optimal growing conditions conducive for improved crop yield [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 stands as attractive technology in modern agriculture, offering several benefits including enhancement of crop yield, improvement in fertilizer use efficiency and the maintenance of optimal nutrient and water levels at distinct crop growth stages [9]. The technique applies both water and fertilizer at a low rate directly to the plant root zone as per crop needs and according to crop developmental phase, thereby resulting in higher yields and better quality of the produce [10]. Further, it can minimize the groundwater pollution due to less leaching losses of fertilizers as compared to excessive irrigation [11]. Fertigation time can be scheduled as often as irrigation, several times per season. Hence, to increase crop yield and water productivity under protected cultivation, there is a need to evaluate the drip irrigation frequency based on climatic conditions and required fertigation frequency [5].

Tomato (*Solanum lycopersicum* L.) is categorized as a low-calorie vegetable, distinguished for its excellent source of dietary fibers, minerals, vitamins and antioxidants [12]. The antioxidants are found to be protective of various types of cancers, such as those affecting the colon, prostate, breast, lung, and pancreas [7]. In the cultivation of greenhouse tomatoes, the indeterminate nature of the crop results in a concurrent occurrence of vegetative and reproductive stages, necessitating a continuous supply of nutrients throughout the growth cycle, to optimize the growth and yield of the crop. Therefore, employing techniques such as fertigation holds considerable promise for enhancing the efficacy of nutrient application in tomatoes under polyhouse [13]. Tomatoes, recognized as a high-value cash crop, exhibit higher nutritional demands (NPK 150:120:60). Under protected conditions, the harvesting is done in 12-15 pickings. The tomato plants are anticipated to demonstrate varying responses to different soil moisture and fertigation levels [4]. Thus, the present study was planned to evaluate the effect of drip irrigation and NPK fertigation levels on soil moisture availability and productivity of tomatoes under polyhouse.

2. MATERIALS AND METHODS

2.1 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 12.20 g kg^{-1}, respectively. 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}).

2.2 Treatment Details

The experiment comprised 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 treatments throughout crop growth period. In nutrient schedules, NPK fertilizer doses calculated as per treatments 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 are given in Tables 1 and 2.

2.3 Soil Water Content and Water Stock

The changes in soil water content were determined by thermo- gravimetric method periodically during crop growth period. The volumetric moisture content (ϴ) for different depths was calculated by multiplying the gravimetric moisture 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.

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*

2.4 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.

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

2.5 Soil Sampling and Analysis

The initial soil samples were collected before transplanting of the tomato, for analyzing various physico-chemical properties of soil. 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 [17].

2.6 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.

2.7 Statistical Analysis

The analysis of variance technique (ANOVA) in completely randomized block design was employed to analyze the data statistically by using statistically software package for agricultural research workers [18].

3. RESULTS AND DISCUSSION

3.1 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 [19].

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 [20].

3.2 Nutrient Uptake

The soil nutrient status at harvest is given from Tables 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 [21,22,23,24].

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 depth (m)		Soil Water Stock 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

DAT: Days after transplanting

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

Nutrient Schedule	Drip Irrigation levels			
	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	

3.3 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 [25,26,23,27,28,29,13]. 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}).

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. [30], Yaghi et al. [31] and Hakim and Chand [32]. 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 [33] where optimal fertigation was a beneficial practice for improving water use efficiency. Similar results were also reported [24]. 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}).

3.4 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 [24] and [34].

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	

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	

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

4. 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 combination for cultivation of tomatoes under a naturally ventilated polyhouse in the Himalayan region. This treatment exhibited higher marketable yield coupled with reduced water consumption, thereby resulting in higher water use efficiency. The I_2NPK_{150} treatment resulted in 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 production under protected conditions in Himalayan region.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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