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Research Paper

Climatological approaches of irrigation scheduling for growing tomato crop under drip irrigation in sub-tropical region of Punjab

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ABSTRACT

A field experiment was conducted at Lovely Professional University, Phagwara, Punjab for two years (2022 and 2023) to study the response of tomato crop to drip irrigation scheduling based on climatological approach viz. Penman-Monteith, Blaney-Criddle and pan evaporation. Result revealed that, the all treatments of irrigation scheduling were found feasible for optimizing tomato yield (30.8 to 44.6 t ha^{-1}), water saving (27 to 50.7%) and water use efficiency (1.31 to 1.61 t ha^{-1}-cm) under drip irrigation over soil moisture depletion approach. In selected region the average daily ET_0 (4.4 to 9 mm day^{-1}) and ET_C (2.5 to 10.8 mm day^{-1}) varies with different growth stages and results varying crop water demand of tomato. This water demand can successfully meet out by applying water at 100 % ET_0 based on Penman-Monteith method with significant crop yield (44.6 t ha^{-1}) and water use efficiency (1.33 t ha^{-1}-cm). Correlation analysis indicated that, in case of other regions where the availability of weather parameters will be limited for irrigation scheduling, the farmer could irrigate their tomato crop at 90% ET_0 based on daily pan evaporation method under drip irrigation. In selected region, the Blaney-Criddle method was found ineffective and shows under and overestimated values of daily ETo during mid stage and late stage which gives more water saving (up to 51%) but reduces significant tomato yield over Pan Evaporation method.

Keywords: Crop evapotranspiration (ET_C), Drip irrigation, FAO-Penman Monteith, Irrigation scheduling, Reference Evapotranspiration (ETo), Tomato.

Tomato (*Lycopersicon esculentum*) is a popular vegetable crop which is grown in Indian, Punjab. In year 2020, world tomato production was 187 MT, with China contributing for 35% of the total, followed by India, Turkey, and the United States (FAOSTAT, 2019). It is a warm season crop. Climatic conditions, crop and soil patterns are the major factors for understanding water requirement in agriculture (Singh *et al*., 2021; Sharma *et al*., 2021). In Indian Punjab, canal water is the major source of irrigation but the supply of canal water at farmer field is limited as per availability of their irrigated area (Garg *et al*., 2022; Changade *et al*., 2023). Farmers are drawing ground water to irrigate crops which does not support sustainable agriculture practices (Garg *et al*., 2022). In Punjab, groundwater resources are exhausting at an alarming rate of 0.54 m annually due to over-exploitation and indiscreet irrigation water policies (Agarwal *et al*., 2020). Each tomato plant needs different water requirement as per its height, climate, and soil type. Therefore, it is essential to irrigate tomato crop through modern irrigation method. Drip irrigation is an effective management approach that has improved the production of vegetable crops (Garg *et al.,* 2022). Irrigation scheduling plays an important role to achieve maximum yield and water use efficiency under drip irrigation (Sharma *et al*., 2021). Now days, in India the water balance method (direct approach) is commonly used for irrigation scheduling under drip irrigation system, (Sharma *et al.,* 2021). This approach gives a general idea of irrigation scheduling especially under climate change scenario, whereas the modern approach of irrigation scheduling which is based on reference evapotranspiration (ET_0) is quite comprehensive (Satpute *et al*., 2021) and is based on daily water loss from soil as well as plant canopy under given climatic conditions. In modern approach, the FAO 56 Penman-Monteith

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equation is weighed for accurate estimation of ETo (Saxena *et al*., 2020). It is directly dependent on meteorological parameters such as radiation, humidity, temperature and speed of wind, along with some crop parameters. The results obtained from past studies revealed that, there is no bound method to estimate ET. Some methods require huge data but considered as accurate, other require less data but considered as approximate (Meshram *et al*., 2010). The complexity associated with the estimation of ETo and crop water demand under limited availability of climatic parameters has led to standardize various method for estimating these parameters over time. The standardization of climatological approaches will give valuable information to raise agricultural water management strategies for batter crop production (Pandey *et al*., 2008; Singh *et al*., 2019). The present study was, therefore, taken up to select an efficient, reliable and economically viable approach of irrigation scheduling in order to irrigate tomato crop in trans-Gangetic region of Punjab for effective water resources management.

MATERIAL AND METHODS

Study area and other experiment details

A field experiment was conducted during 10 March to 10 June 2022 and 2023 at Research Farm, Lovely Professional University, Phagwara, Punjab (latitude 31.25° N and longitude 75.70° E along with altitude of 280 m above mean sea level).

Experimental treatments for tomato crop

T_1: Irrigation at 100 % of ET_0 based on FAO Penman-Monteith equation under drip irrigation

T_2: Irrigation at 75 % of ET_0 based on FAO Penman-Monteith equation under drip irrigation

T_3: Irrigation at 100 % of ET_0 based on Blaney–Criddle equation under drip irrigation

T_4: Irrigation at 85 % of ET_0 based on Blaney–Criddle equation under drip irrigation

T_5: Irrigation at 100 % of E_{pan} measured through Class A pan evaporimeter under drip irrigation.

T_6: Irrigation at 90 % of E_{pan} measured through Class A pan evaporimeter under drip irrigation.

Control: Irrigation through drip irrigation (At 50% depletion in field capacity)

ET_0 = Reference evapotranspiration (mm day-1)

E_{pan} = Pan Evaporation (mm day-1)

In this study six drip irrigated treatments (having three climatological approaches of irrigation scheduling i.e FAO-Penman Monteith, Blaney Criddle and Pan Evaporation methods) and one control plot were taken in random block design with four replications. Drip irrigation method was also used to irrigate the tomato crop at 50% depletion in field capacity of soil in control plot. While, for remaining plots (i.e: treatment T_1 to T_6), the irrigation water was supplied on the basis of actual crop evapotranspiration (which was estimated through three different approaches) as per respective treatment through drip irrigation. The weather data for calculating crop water requirement on daily basis was acquired from the meteorological observatory of Punjab Agricultural University during the whole growing period.

Methods of estimation of ETo

The Penman-Monteith Method (Allen *et al.,* 1998), Blaney-Criddle method [$ET_o = p\,(0.457{\cdot}T_{mean} + 8.128)$, where p is the average daily percentage of annual daytime hours due to latitude of selected region (it was taken as 0.27, 0.29, 0.31 & 0.32 for March, April, May & June months respectively), & T_{mean} is mean air temperature (°C)] and FAO Pan Evaporation Method [$ET_o = E_{pan} \times K_p$, where Epan = Pan Evaporation (mm day^{-1}) and Kp = Pan coefficient] were selected for calculating daily ET_0. The crop evapotranspiration (ET_c) was calculated by Eq 1. The pan coefficient (K_p) for calculating crop evapotranspiration by using pan evaporation data was taken as 0.7.

Further the estimation of crop water requirement during whole period of tomato crop was done by using Eq. 2, for fixation of irrigation scheduling of tomato crop under drip irrigation for selected region.

$$ET_C = ET_0 \times K_C \quad (1)$$

$$V = \sum (ET_c \times Sp \times Sr \times WP) \quad (2)$$

Where,

V = estimated crop water demand (litre $day^{-1}plant^{-1}$), ET_c =Crop evapotranspiration (mm day^{-1}), ET_0 = Reference evapotranspiration (mm day^{-1}), Kc = Crop coefficient (taken as per local recommendation), Sp = Plant spacing, m, Sr = Row spacing, m, Wp = Wetted area (90%) and ER = Effective rainfall, mm

In this study, based on USDA S.C.S method the effective rainfall (ER) was calculated by on monthly basis by following equation:

$$ER = P_t\left[\frac{125 - 0.2 \times Pt}{125}\right] \text{ for } Pt < 250 \text{ mm}$$

Where, P_t - total rainfall, mm

Crop observation

The five plants were selected from each treatment in all replication. The plant height and total number of branches were taken at the time of last harvesting from tomato plant while number of fruit and fruit yield per plant were noted at the time of each harvesting. The yield of fruits per plot (kg) was weighed separately at the time of each harvesting for each treatment in all replications and then it was converted in to total yield of fruits per hectare (t ha^{-1}). Water use efficiency is defined as the ratio of yield to the total depth of irrigation. It was calculated by Eq. 3 (Sharma *et al.,* 2021).

$$\text{Field water use efficiency (\%)} = \frac{\text{Crop yield (t ha}-1)}{\text{Total depth of irrigation (mm)}} \times 100 \quad (3)$$

Correlation analysis

Analysis of variance technique was taken to analyze the

Table 1: Stage-wise daily weather parameters in selected study area.

	Initial stage			Mid stage			Late stage		
	2022	2023	Mean	2022	2023	Mean	2022	2023	Mean
Maximum temp. (^{0}C)	32.3	26.6	29.45	39.7	34.9	37.3	39.6	36.5	38.05
Minimum temp. (^{0}C)	22.3	14.6	18.45	29.2	19.1	24.15	30.7	25.1	27.9
Maximum RH (%)	53.5	85.6	69.55	40	61.9	50.95	33.8	51.4	42.6
Minimum RH (%)	41.3	55.6	48.45	22.8	24.3	23.55	35.5	37	36.25
Wind speed (km hr^{-1})	3.1	3.3	3.2	7	4.5	5.75	8.4	5.9	7.15
Sunshine hours	9.3	4.8	7.05	11.3	9.2	10.25	11.8	9.8	10.8

Table 2: Stage-wise daily average ET_0 and ET_c estimated through different climatological approaches.

Treatments	Initial Stage			Mid Stage			Late Stage		
	2022	2023	Mean	2022	2023	Mean	2022	2023	Mean
Average reference evapotranspiration (mm day-1)									
FAO-Penman Monteith	4.9	4.2	4.6	9.5	8.5	9	8.9	8.1	8.5
Blaney Criddle	5.6	4.8	5.2	7.1	6.1	6.6	7.6	7.0	7.3
Pan Evaporation	4.6	4.1	4.4	8	7.8	7.9	7.2	8.1	7.6
Average crop evapotranspiration (mm day-1)									
FAO-Penman Monteith	2.9	2.5	2.7	11.4	10.2	10.8	6.2	5.7	6.0
Blaney Criddle	3.4	2.9	3.2	8.5	7.3	7.9	5.3	4.9	5.1
Pan evaporation	2.6	2.4	2.5	9.5	9.4	9.5	5.0	5.7	5.4
Average crop coefficient (Kc)		0.6			1.2			0.7	

research data to randomized block design. The linear regression analysis was done to check the accuracy to estimate ET_0 by Blaney-Criddle and pan evaporation methods as compared to Penman-Monteith method.

RESULTS AND DISCUSSION

The result obtain from both years indicates that, during initial stage the average daily temperature was recorded minimum and relative humidity was recorded maximum as compared to remaining growth stages of tomato crop (Table 1). The mean data of weather parameters during both years shows that the daily value of sunshine hour and wind speed varies from 4.3 to 12.8 and 1.85 to 14.6 km h^{-1}, respectively during whole growth stages. The minimum and maximum daily pan evaporation was recorded as 2.9 mm day^{-1} and 14.5 mm day^{-1} at initial stage and mid stage respectively. The uneven trend of daily weather parameters was found due to industrialization and temporal variation in selected area and it is significantly affecting the actual ET_0 which plays an important role for deciding optimum amount of irrigation water as well as appropriate time of irrigation (i.e irrigation scheduling) during whole growing period.

On the basis of mean data of both years, the average daily ETo which was estimated by Penman-Monteith, Blaney–Criddle and Pan Evaporation methods was varies from 4.6 to 9, 6.6 to 7.3 and 4.4 to 7.9 mm day-1, respectively whereas ETc was varies from 2.7 to 10.8, 3.2 to 7.9 and 2.5 to 9.5 mm day-1, respectively during whole growing period (Table 2). The ET_0 and ET_c were recorded maximum at mid stage of crop growth. It is because of high atmospheric temperature, more sunshine hours and high wind speed. This is mainly owing to the maximum vegetation growth for tomato plant, in addition to the climatic conditions in this stage. Tomato crop performance is very sensitive to irrigation water therefore it is very essential to calculate daily irrigation water requirement in order to irrigate tomato crop as per their varying water demand at different growth stages under drip irrigation. In water scare region this concept may result high water use efficiency (by reduction in total water applied and increment in crop yield) and irrigation water saving. Similar finding was reported by Singh *et al*. (2021) for field crop which report the variation in ET_0 at different growth stages.

On the basis of correlation analysis during both years (Fig 1a and 1b), Pan Evaporation method has most similarity with Penman- Monteith-FAO-56 [R^2 = 0.967 (in year 2022) and 0.893 (in year 2023)] for estimating ET_0 which indicate that, the pan evaporation method can use for irrigation scheduling under the condition of limited availability of daily weather data in trans-Gangetic region of Punjab. Similar trend was reported by Jhadav *et al*. (2015) for Rahuri region in their study. In this region Blenny Criddle method was found slightly accurate approach for irrigation scheduling [R^2 = 0.409 (in year 2022) and 0.500 (in year 2023)]. The similar value of correlation coefficient (R^2 =0.432) has reported by Jadhav *et al.* (2015) for estimating actual ET_0 through Blaney-Criddle method and Penman-Monteith method for Rahuri region of Maharashtra. The Blaney-Criddle method is simple and provides a rough estimate or "order of magnitude" only. In this selected region the Blaney-Criddle method is ineffective which shows underestimated and overestimated values of daily ETo during mid stage and late stage. It was probable due to direct impact of temperature for calculating evapotranspiration. The result is in line with findings of Meshram *et al*. (2010) which have reported that, the Blaney Criddle method is not closely related with Penman Monteith method for estimating reference evapotranspiration.

Effect on growth and yield contributing parameters of tomato crop

On the basis of mean data of both years, the obtained

Table 3: Effect of different treatment on growth and yield contributing parameters of tomato crop during both years

Treatments	Plant height (cm)			Number of branches per plant			Number of fruit per plant			Fruit yield (kg) per plant		
	Y1	Y2	Mean	Y1	Y2	Mean	Y1	Y2	Mean	Y1	Y2	Mean
T_1	97	92.2	94.6	15	11	13	43	38	40.5	2.2	2.5	2.35
T_2	91	86.1	88.5	15	10	12.5	36	34	35	1.8	1.6	1.7
T_3	89	83	86	11	10	10.5	36	29	32.5	1.6	1.6	1.6
T_4	84	85	84.5	9	9	9	34	29	31.5	1.4	1.3	1.35
T_5	94	90	92	13	12	12.5	39	36	37.5	2.4	2.1	2.25
T_6	83	80	81.5	10	9	9.5	32	31	31.5	1.4	1.6	1.5
Control	87	82	84.5	8	8	8	29	27	28	1.2	1.6	1.4
SEM	0.53	1.87	1.2	0.38	0.71	0.54	0.97	1.31	1.14	0.08	0.1	0.09
CV (%)	2.19	4.34	3.2	6.17	14.4	10	5.29	8.2	6.7	9.6	11.6	10
CD (P=0.05)	1.6	3.44	2.52	1.14	2.16	1.65	2.91	3.9	3.4	0.25	0.31	0.28

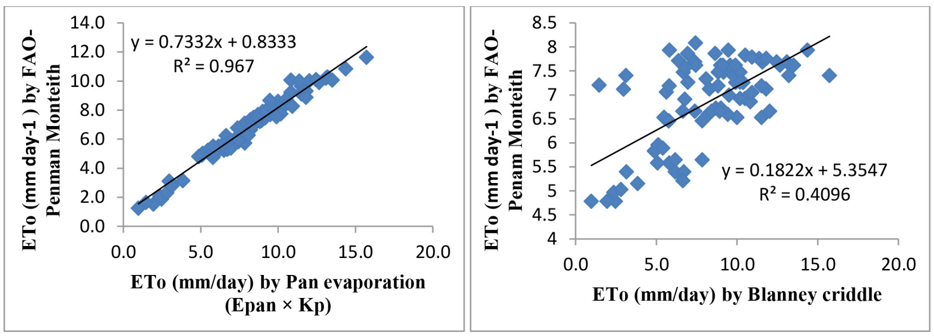

Fig. 1a: Correlation between estimated ET0 by Penman-Monteith-FAO-56 and other (Pan evaporation and Blaney-Criddle) methods during year 2022.

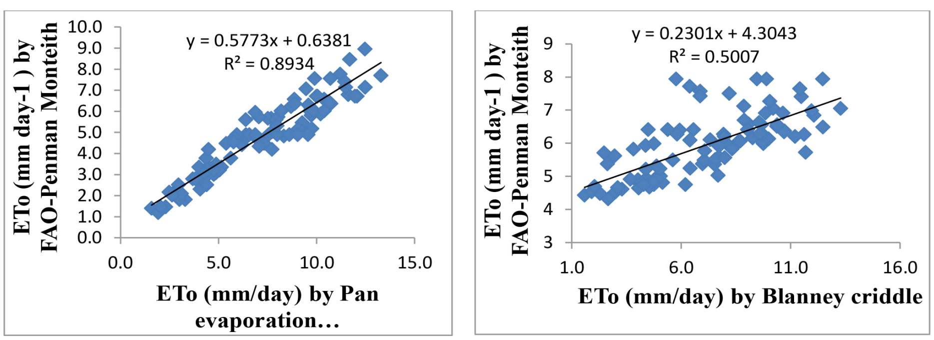

Fig. 1b: Correlation between estimated ET0 by Penman-Monteith-FAO-56 and other (Pan evaporation and Blaney-Criddle) methods during year 2023.

result indicates that, the plant height, number of branches per plant, number of fruits per plant and fruit yield per plant were significantly affected by climatological approaches of irrigation scheduling in selected region as compared to traditional or direct approach of irrigation scheduling which was taken in control plot. The mean data of both years (Y1 and Y2) presented in Table 3 indicates that, the plant height, number of branches per plant, number of fruit/plant and fruit yield per plant were recorded maximum as 94.6 cm, 13, 40.5 and 2.35 kg/plant, respectively under treatment T_1 (rrigation at 100 % of ET_0 based on FAO Penman-Monteith equation under drip irrigation) followed by treatment T_5. It was due to availability of optimum moisture content in plant rootzone by supplying water on the basis of daily water loss from soil as well as plant canopy as per treatment. The minimum values of plant height, number of branches per plant, number of fruit/plant and fruit yield per plant were recorded as 81.5 cm (under T_6), 8, 28 and 1.4 kg per plant under control plot.

In case of same irrigation level (irrigation at 100% ET_0) under drip irrigation method, the plant growth and yield contributing parameters of tomato crop were significantly affected by different climatological approaches of irrigation scheduling (estimation of ET_0 by FAO-Penman Monteith, Blaney Criddle and Pan evaporation method) in selected study area which clearly indicates that, in case of full or limited availability of daily weather parameters (for estimation of irrigation water requirement), the adoption of appropriate climatological approach of irrigation scheduling is very important for irrigating tomato crop with significant plant growth and yield contributing parameters over traditional method of irrigation scheduling (soil moisture depletion based).

Table 4: Effect of different treatment on yield, irrigation water requirement, water saving and water use efficiency of tomato crop during both years

Treatment	Crop yield ($t\ ha^{-1}$)			Total irrigation water applied (mm)			Effective rainfall (mm)			Total amount of water supplied (mm)			Irrigation water saving (%) over control			Water use efficiency ($t\ ha^{-1}$-cm)		
	Y1	Y2	Mean	Y1	Y2	Mean	Y1	Y2	Mean	Y1	Y2	Mean	Y1	Y2	Mean	Y1	Y2	Mean
T_1	48.3	44.6	46.4	359.0	328	343.5	7.2	34.2	20.7	366.2	362.2	364.2	26.70	27.40	27.05	1.31	1.35	1.33
T_2	44.1	40.2	42.1	269.0	246	257.6	7.2	34.2	20.7	276.4	280.2	278.3	45.00	45.50	45.25	1.59	1.63	1.61
T_3	37.0	38.0	37.5	290.2	255	272.5	7.2	34.2	20.7	297.2	289.2	293.2	40.80	43.50	42.15	1.24	1.49	1.36
T_4	31.0	30.8	30.9	246.5	217	231.7	7.2	34.2	20.7	253.7	251.2	252.4	49.60	51.90	50.75	1.22	1.41	1.31
T_5	42.2	43.2	42.7	291.6	311	301.3	7.2	34.2	20.7	298.8	345.2	322.0	40.40	31.10	35.75	1.41	1.38	1.39
T_6	40.1	37.0	38.5	262.4	280	271.2	7.2	34.2	20.7	269.6	314.2	291.9	46.40	38.00	42.20	1.49	1.32	1.40
Control	27.0	28.0	27.5	490.0	452	471.0	7.2	34.2	20.7	497.2	486.2	491.7				0.54	0.61	0.58
SEM	1.36	2.22	1.7															
CV (%)	6.72	11.9	9.3															
CD (P=0.05)	4.1	6.7	5.4															

Effect on yield, water saving and WUE of tomato crop

The data related to total amount of irrigation water applied, water saving, crop yield and water use efficiency are presented in Table 4. In this study it was noted that in year 2022, the irrigation water requirement was recorded lesser than it was in year 2023. Crop water requirement is basically the amount of water which is required by specific crop for its batter performance under given climatic conditions. It is a sum of irrigation water requirement and effective rainfall so in both years, the crop water requirement was almost similar but due to more availability of effective rainfall in year 2023, the irrigation water requirement was recorded less which results more water saving and water use efficiency as compared to year 2022. On the basis of mean data of both years, the total amount of irrigation water supplied was estimated as minimum under treatment T_4 (217 mm) followed by T_2 (278.3 mm) and T_6 (280 mm). The irrigation water requirement for treatment T_3 and T_4 was found relatively lesser than other treatment. This variation was due to that in these treatments, the climatological approach of irrigation scheduling was based only on daily atmospheric temperature data which result slightly less value of reference evapotranspiration while in other approaches, the daily reference evapotranspiration influenced by various weather parameters like humidity, sunshine hour and wind speed. The total irrigation water requirement was recorded maximum as 490 mm under control plot. The similar trend of crop water requirement has already reported by Singh *et al.,* (2021) for pea crop for Manipur region. The crop yield (30.8 to 44.6 $t\ ha^{-1}$), irrigation water saving (27 to 50.7 %) and water use efficiency (1.31 to 1.61 $t\ ha^{-1}$-cm) were found superior under drip irrigated treatments as compared to control plot (Table 3). It was due to more availability of moisture in soil as well as low wastage of water and nutrient due to infiltration, percolation and surface evaporation over flood irrigation. Water act as an important variable in photosynthesis so continuous availability of moisture content in plant rootzone under drip irrigation treatments results less chances of water stress and improve photosynthesis rate which can be a reason for high crop yield. Among all the drip irrigated treatments, the crop yield, was recorded highest under T_1 (44.6 $t\ ha^{-1}$) followed by T_5 (42.7 $t\ ha^{-1}$) and T_2 (42.15 $t\ ha^{-1}$). The crop yield under treatment T_5 (42.15) was recorded at par with crop yield obtained under treatment T_2 (42.15 $t\ ha^{-1}$) which clearly indicates that, for irrigation scheduling of tomato crop in trans-Gangetic region of Punjab, the pan evaporation based climatological approach can effectively use under limited availability of daily weather parameters instead of FAO-Penman Monteith method with the significant crop yield (42.7 $t\ ha^{-1}$) and water use efficiency (1.395 $t\ ha^{-1}$-cm). The minimum yield (30 $t\ ha^{-1}$) was recorded under control plot which was at par with treatment $T_{1,}$ having irrigation at 85 % of ET_c based on Blaney–Criddle equation under drip irrigation. Which is clearly indicates that, under limited availability of weather data and climate change scenario, Blaney-Criddle equation will not be more effective for significant crop yield as compared to other climatological approaches of irrigation scheduling in-trans-Gangetic region of Punjab. It was probably due to only the direct impact of daily temperature on estimation of ETo and ETc. The water use efficiency was recorded highest under T_2 (1.61 $t\ ha^{-1}$-cm) followed by T_6 (1.4 $t\ ha^{-1}$-cm).

The irrigation water saving was found highest as 50.7 % under treatment T_4 as compared to control plot but in this treatment crop yield was significantly found significantly lesser than other drip irrigation treatments having different climatological approaches of irrigation scheduling and irrigation levels. Overall, it can be stated that drip irrigation (which offers a more favorable soil moisture regime than flood irrigation) led to improved tomato fruit development and high irrigation water saving and water use efficiency. The result is in line with Singhal *et al*, (2021) and Sharma *et al*, (2021). The irrigation water saving and water use efficiency under drip irrigation were highest due to precious application water as per crop water requirement as well as at right time. Timely supply of right quantity of water to part of the root system has effectively provided water to tomatoes.

CONCLUSION

In selected study area all the climatological of approaches of irrigation scheduling were found feasible for getting batter crop yield, irrigation water saving and water use efficiency of tomato crop under drip irrigation. In water scare regions of Indian Punjab (where availability of fresh water resources is limited and quality of ground water is very poor), the climatological approaches of irrigation scheduling will be more effective for deciding the irrigation schedule for tomato crop grown under drip irrigation with significant increase in plant growth (11 %), crop yield (68%) and irrigation water saving (50.7 %) over soil moisture depletion approach. In subtropical region of Punjab, the Blaney-Criddle method was found as ineffective which shows underestimated and overestimated values of daily ETo during mid stage and late stage. The climatological approach of irrigation scheduling can be suitably used to estimate the varying water demand of tomato crop at various growth stages and it may further assist the irrigation manager, farmer and policy makers for conserving available fresh water resources as well as to improve water productivity. The findings of this research work can also be used in other water scare regions of Punjab having similar climatic condition and management scenario.

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