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Impact of drip and furrow irrigation on tomato yield under mulch and non-mulch conditions

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Abstract

Field experiments were conducted for two years (2012 and 2013) on sandy loam soil to study the response of furrow irrigation and variable water supply by drip irrigation on yield and water use of tomato crop under both plastic mulch and non-mulch conditions. The study was conducted in randomized block design with eight treatments having three replications each. Out of the eight treatments, six comprised of 100, 80 and 60% crop evapotranspiration (ET_c) replenishment with mulching and non-mulching conditions irrigated by drip irrigation system and two were furrow irrigation with mulching and non-mulching conditions. The mean yield and water-use efficiency of crop were found to be significantly maximum (19.0 $t\ ha^{-1}$ and 0.772 $t\ ha^{-1}\ cm^{-1}$, respectively) for the treatment with 100% ET_c replenishment irrigated by drip system with mulching (T_5) as compared to other treatments. The study revealed that drip irrigation gave more yields and water-use efficiency of the crop than the furrow irrigation. Further, it was observed that mulching resulted in getting more yield and water-use efficiency than non-mulching condition. The treatment T_5 increased the mean yield and water-use efficiency by 53.2 and 89.2% besides saving 19.2% costly irrigation water than the conventional furrow irrigation without mulching as practiced by most of the farmers.

Keywords: Irrigation water management, furrow irrigation, crop evapotranspiration, drip irrigation, furrow irrigation

Introduction

Land and water are the two important natural resources for sustenance of agricultural production in any country. Out of these two, water is very important influencing production and productivity of any crop. It, being a limited resource, its efficient utilization is basic to the survival of mankind. Though India is blessed with abundant water resources, however, due to various physiographic constraints, existing legal constraints and the present method of utilization, the utilizabale water for irrigation is getting exhausted. Further, the increasing demand of water for expanding urbanization and industrialization will make the situation more critical since the share of water for irrigation will dwindle in near future. It is therefore essential to formulate an efficient and economically viable irrigation management strategy in order to irrigate more land area with the existing water resources (Panigrahi, *et al.*, 1992). Improper irrigation management practices not only waste the scarce and expensive water resources but also decrease the crop yield (Imtiyaz *et al.*, 2000; Tiwari *et al.*, 1998) [13]. In the present day context, improvement in irrigation practices including schedules and methods are needed to increase the crop production and to sustain the productivity levels.

Furrow irrigation is the conventional method widely used to irrigate most of the vegetable crops grown in Odisha, India. But this method uses more water as compared to other high take irrigation methods like sprinkler, drip etc. Many researchers have reported higher application efficiency of drip irrigation system over the conventional furrow irrigation system (Tiwari *et al.*, 1998; Hanson *et al.*, 1997; Fekadu and Teshome 1998) [24, 12, 10]. Sivanappan and Padmakumari (1980) [23] compared drip and furrow irrigation systems in vegetables and found that there was savings of 67 to 80% irrigation water as compared to surface irrigation methods. Based on the study conducted at Rahuri, India, Khade (1987) [14] reported 60% higher yield of okra with water saving of 40% under drip irrigation as compared to furrow irrigation. Economic evaluation of drip irrigation in fruit crops (coconut, mango and sapota) in Odisha, India revealed that this system conserved considerable amount of water and resulted better returns despite higher initial investment (Behera and Sahoo 1998) [7]. The response of banana to drip irrigation in terms of yield improvement was found to be different in different agroclimatic and soil conditions in India (Shrivastava *et al.*, 1999; Bharambe *et al.*, 2001; Agrawal and Agrawal 2005) [22, 8, 1].

Irrigation scheduling plays a crucial role in agricultural water management. It is imperative to study the different irrigation schedules by drip irrigation and suggest the most efficient irrigation schedule that would give the highest yield and water-use efficiency of the crop. Field experiments in the northern region of Allahabad, India were conducted by Denis and Kumar (2007) [9] to study the effects of 8 levels of pan evaporation replenishments (25, 50, 75, 100, 125, 150, 175 and 200%) on marketable yield, irrigation production efficiency and economic return of potato under drip irrigation. The highest mean marketable yield and irrigation production efficiency were observed to be 48.98 t ha^{-1} and 106.26 kg m^{-3}, respectively at 150% pan evaporation replenishment. Irrigation at the said level of pan replenishment also gave highest economic return and benefit-cost ratio. Asik *et al.* (2014) [5] conducted experimental study to find out the irrigation water requirement of Memecik olive trees with five treatments that received an amount of water equivalent to 25, 50, 75, 100 and 125% of the five-day cumulative evaporation from class A pan. They reported that Memecik olive trees should be scheduled based on the amount of irrigation water equivalent to25% of the five-day cumulative evaporation from class a pan so that there would be considerable savings of irrigation with minimal effects on yield.

Use of soil cover and mulching is also known to be beneficial chiefly through their influence on soil moisture conservation, solarization and control of weeds. Beneficial response of plants to mulch includes early production, more yield and reduced insect and disease problems (Barua and Phookan 2009; Pattanaik *et al.*, 2003) [6, 19]. Linear Low Density Poly Ethylene (LDPE) plastic films has been proved better mulch because of its puncture resistance quality, thinness and lower cost (Shrivastava *et al.*, 1999; Paul *et al.*, 2013) [22, 20]. Tiwari *et al.* (1998) [24] reported that 100% irrigation requirement met through drip irrigation along with black plastic mulch gave the highest yield of okra (14.51 t/ha) with 72% yield increase as compared to furrow irrigation.

Presently in India 7.49 million ha area is cultivated with vegetable with an annual production of 116.03 million tonnes. It is estimated that, by 2020 AD the vegetable demand of the country would be around 135 million tonnes. The working group on horticulture constituted by the Planning Commission had recommended deployment of hi-tech horticulture and precision farming for maximizing the production in horticultural sector. Hi-tech interventions in horticultural crops proposed by National Committee on Plasticulture Applications in Horticulture (NCPAH), Govt. of India are drip irrigation and *in-situ* moisture conservation through plastic mulching (Samuel and Singh 2004) [21].

Tomato (*Lycopersicon esculentum*) is an important vegetable crop grown in almost all parts of India and is one of the most preferred vegetable crops in Odisha (eastern state of India). Due to lack of information on irrigation management techniques, the average yield of the crop in Odisha is very low because of either excess or deficit soil moisture. The crop is generally grown with furrow irrigation, which has low application efficiency. Many farmers in the state are now getting interested to grow the crop with drip irrigation. Government is also offering financial assistance to farmers to use this technique especially fruits and vegetable crops. However, some farmers in the state are reluctant to adopt drip technology due to lack of information on irrigation scheduling techniques. Not much information on seasonal water requirement of tomato by drip irrigation is also available. Hence, the present study was undertaken to study the response of tomato to drip under different irrigation schedules and compare the result with furrow irrigation under mulch (black plastic much) and non-mulch conditions and suggest the efficient irrigation schedule that would give the highest yield and water-use efficiency of the crop.

Materials and Methods

Field experiments were conducted in farmers' field for two years in winter 2012 and 2013 at Barahguda village, Sambalpur, Odisha. The latitude, longitude and altitude of the study area are 20^0 21' N. 80^0 55' E and 178.8 m above mean sea level, respectively. The area comes under the sub-humid climatic condition. The total rainfall in the study area during crop growing season (8th January to 3rd April) were 30.0 and 28.0 mm, respectively occurring in 4 rainy days in each year. The mean daily air temperature during the study period ranged from 15.8°C to 31.3°C and 16.1°C to 29.5°C and mean daily relative humidity ranged from 45.5 to 68.7% and 47.2% to 70.5% in 2006 and 2007, respectively.

Soil texture of the study area is sandy loam. Average values for bulk density, volumetric moisture content at field capacity and permanent wilting point, and final steady state infiltration rate are 1.55 gm cm^{-3}, 26%, 10%, and 10 mm hr^{-1}, respectively. Average pH, EC, and organic carbon were 6.3, 0.09 dS m^{-1} and 0.51%, respectively.

The experimental technique followed eight treatments having three replications each and the design followed was randomised block design. The eight treatments were:

T_1 = drip irrigation at 100% crop evapotranspiration (ET_c) replenishment without mulch
T_2 = drip irrigation at 80% ET_c replenishment without mulch
T_3 = drip irrigation at 60% ETc replenishment without mulch
T_4 = furrow irrigation at 1.2 IW: CPE (IW = irrigation water of depth 5 cm and CPE = cumulative pan evaporation) without mulch
T_5 = drip irrigation at 100% crop evapotranspiration (ET_c) replenishment with black plastic mulch
T_6 = drip irrigation at 80% ET_c replenishment with black plastic mulch
T_7 = drip irrigation at 60% ET_c replenishment with black plastic mulch and
T_8 = furrow irrigation at 1.2 IW: CPE with black plastic mulch

In the experiment, black colour low density poly-ethylene (LDPE) film of 50 micron thickness (here in called as black plastic mulch or simply mulch) was used in the plots where mulching was required as part of treatments (treatments T5 to T8). In the present experimental study, the furrow irrigation schedule of 1.2 IW: CPE which is recommended to the farmers for use in tomato (Anonymous 2004) was taken as control study to compare the water requirement and water-use efficiency of tomato by drip and furrow irrigation system.

Tomato variety Arjun was planted in all the treatments with 75 cm spacing from row to row and 60 cm spacing from plant to plant. In furrow treatment, irrigation was applied to each furrow. Furrows were laid at 0.25% bed slope. Seedlings of 25 days duration were planted in plots with both drip and furrow treatments. In case of drip irrigation, lateral spacing of the drip laterals were 1.5 m, emitter/dripper spacing was 0.60 m. There were two crop rows per each lateral and one emitter/dripper per plant. The net plot area of all treatments was 6 m x 3 m. Buffer spaces of 0.5 m width were left in between each two plots to minimize the chances of moisture movement from one treatment to the other or from one replication to the other. Irrigation interval to drip was once in 2 days. Irrigation was supplied from a bore well by a 1.5 HP submersible pump.

The furrows had dikes at the downstream end to prevent runoff. Polyethylene sheet was inserted to a depth of 60 cm in the inner side of dikes of all the plots to prevent lateral seepage. In furrow treatments, 5 cm irrigation (IW = 5 cm) was applied to the crop irrespective of crop growth stage when CPE was 42 mm (IW: CPE = 1.2). CPE was taken as the sum of daily pan evaporation after deducting the rainfall received subsequent to the previous irrigation. Tomato (var.-Arjun) of 86 days duration was planted on 8th January and harvested on 3rd April of both the years. Application of N, P, and K fertilizers were 150, 100, and 100 kg/ha, respectively. Nitrogen was applied 50% as pre-planting and 50% as top-dressing one month after planting. Phosphate and potash applied were 100% pre-planting each. All pre-planting fertilizers were applied in pits where as top dressing fertilizer was applied as ring placement in all drip and furrow treatments.

Drip irrigation was scheduled once in two days based on two previous days' crop evapotranspiration data at 100, 80 and 60% level. Depth of irrigation applied by drip to each plant in every 2 days (*d*) for treatments T_1 and T_5 were computed as (Anonymous 2002) [3]

$$d = \text{Two days CPE} \times Kp \times Kc = ET_c \qquad (1)$$

Volume of irrigation to each plant was computed as

$$V = \text{Two days CPE} \times Kp \times Kc \times A \times Wp = ET_c \times A \times Wp \qquad (2)$$

where *V* is volume of water (lit), *CPE* is cumulative pan evaporation (mm), *Kp* is pan coefficient, *Kc* is crop coefficient, ET_c is crop evapotranspiration (two days value, mm), *A* is area around each plant served by the emitter for irrigation (m^2) and *Wp* is wetted percentage.

Volume of irrigation water applied to each plant by drip for treatments T_2 and T_6 were 80% of the value computed by Eq. (2) whereas for treatments T_3 and T_7 it was 60% of the value computed by Eq. (2). The net irrigation volume at each irrigation timing for all the treatments was determined after deducting the rainfall that has been contributed during each irrigation cycle. Value *Kp* for the study area was assumed 0.8 (Michael 1981). Based on the field experiment, the values of *Kc* of tomato for crop establishment (15 days after planting, DAP, crop development (30 DAP), mid season (26 DAP) and maturity stages (15 DAP) were taken as 0.45, 0.75, 1.10 and 0.65, respectively (Anonymous 2004). The value of *Wp* was assumed as 0.5 during the crop establishment stage and 0.75 during other stages (Anonymous 2002). Since, during the establishment stage, crop coverage was less requiring less irrigation, *Wp* was assumed a low value (0.5) compared to other stages. The area around each plant served by emitter for irrigation was estimated as $A = 0.75 \text{ m} \times 0.60 \text{ m} = 0.450 \text{ m}^2$.

Operating duration of each emitter was estimated as:

$$\text{Operating duration} = V / (\text{Number of emitters/plant} \times \text{emitter discharge rate}) \qquad (3)$$

where operating duration is in hours, *V* is volume in lit and emitter discharge rate is in lit hr^{-1}. Volume of irrigation water and hence the operating duration at each irrigation thus varied according to evaporation rate, crop growth stage as well as treatment irrigation schedules i.e. percentage level of crop evapotranspiration replenishment i.e. 100, 80 and 60% level. In the experiment, number of emitters/plant was kept as one and the emitter discharge rate was kept fixed for all treatments, which was 4 lit hr^{-1}.

Design and Layout of Drip System

From the water source (bore well), the irrigation water was pumped with a submersible 1.5 HP pump and was supplied to the plots through PVC main pipe (63 mm diameter) fitted with gate valve. Water was supplied to the drip treatments through PVC main pipe after passing through a screen filter. From the main line, sub mains of PVC pipes (40 mm diameter) were taken off. From the sub mains, laterals of 12 mm diameter were taken at 1.5 m apart. Drippers/emitters were connected to laterals through small size in built PVC pipes. Laterals were laid at the center of two rows and there was one emitter/dripper per plant. Lateral tapes were fixed in each lateral to control irrigation as per treatments. The discharge rate of each emitter was kept fixed for all treatments and was 4 lit/hr. There were 10 plants in each row and hence 20 emitters per lateral and so the total discharge rate of each lateral was 80 lit/hr. A parshall flume was used to measure the irrigation water supplied to all plots in the furrow treatments.

The water requirement of the crop was computed as the sum of the irrigation water, effective rainfall, and soil moisture contribution from the effective root zone depth of the crop. The effective root zone depth of the crop is assumed as 60 cm. Soil moisture contribution from the effective root zone was measured and the crop evapotranspiration (*etc.*) was estimated (Ahmed and Mishra, 1987) [2] as follows

$$ET_c = P - R + I_r \pm \Delta S - D \qquad (4)$$

where *P* is precipitation, I_r is irrigation, *R* is surface runoff, ΔS is change in profile soil moisture storage, and *D* is downward flux below the crop root zone (deep percolation). In the above equation, groundwater contribution to crop root zone was neglected since groundwater table was at more than 1.5 m below crop effective root zone.

The component (*P* - *R*) may be termed as effective rainfall. In both the two years of the experiments, average seasonal rainfall during the crop growth period was only 3.0 cm (occurring in 4 rainy days) and there was no day having rainfall more than one cm. Further, the potential evapotranspiration during the cropping season was higher and so it was therefore assumed that rainfall was 100% effective (Michael, 1981).

Deep percolation was estimated (Ahmed and Mishra, 1987) [2] as

$$D = K_\theta \, \delta h / \delta z \qquad (5)$$

where *D* is deep percolation (mm d^{-1}), $\delta h/\delta z$ is water potential gradient between 60 cm and 75 cm depth below soil surface, and K_θ is unsaturated hydraulic conductivity (mm d^{-1}), which is a function of volumetric soil moisture, θ.

During the crop growing period, soil moisture contents on per cent basis were determined from 0-15 cm, 15-30 cm, 30-45 cm and 45-60 cm layers of each plot on every second day by tensiometers. These values were converted to percent volumetric basis (θ) by multiplying the respective values with bulk density of soil of respective layer. Soil water content (*SWC*) in each layer was calculated by multiplying the soil layer thickness (15 cm) with θ. Finally total *SWC* in the effective root zone depth of crop was calculated by adding the values of *SWC* from the four layers. Soil moisture characteristic curves and saturated hydraulic conductivity were measured by standard laboratory methods for the experimental site. The functional relation between K_θ and θ was estimated using the method of Green and Corey (1971) [11]. Tensiometers were also placed at 60 cm and 75 cm depths in each plot for determination of water potential gradient.

Data on crop yield were recorded for all treatments. Water-use efficiency (WUE) of the crop for each treatment was computed from yield and water requirement data.

Results and Discussion

Irrigation Requirement and Water Use

Water requirement including irrigation requirement of the crop for all the treatments in both the years of the study period is given in Table 1. Irrigation requirement of furrow treatment was found to be higher than the drip treatments in both the years. The irrigation requirement in case of furrow treatments was found to range from 30.0 to 30.6 cm in both the years with a mean value of 30.3 cm. In case of drip irrigation, the treatment with 100% ETc was observed to require the highest irrigation (irrigation ranging from 24.0 to 24.8 cm with a mean value of 24.4 cm) whereas the treatment with 60% ETc was found to require the lowest irrigation (ranging from 17.2 to 18.0 cm with a mean value of 17.6 cm) in both the years of experiments. The mean irrigation requirement of drip treatments with 100, 80 and 60% levels of ETc were obtained as 24.4, 20.5 and 17.6 cm, respectively (Table 1). Irrigation requirement for 100% levels of ETc treatment was observed to be the maximum than all other drip treatments since more amount of irrigation water was applied to the plants at this level. Total mean seasonal irrigation requirement of crop at 100% levels of ETc was 38.63% more than that at 60% level of ETc and 19.02% more than that at 80% level of ETc. However, compared to the furrow treatment, all the drip treatments needed less irrigation; mean seasonal values of savings of irrigation water in drip treatments ranging from 19.50 to 41.91% as compared to furrow treatment.

Water requirement/water use of the crop with furrow treatment was also found to be maximum as compared to any drip treatment in both the years of the study. The mean water requirement for the furrow treatment without mulch (treatment T4) and with mulch (treatment T8) were found to be 30.4 and 29.3 cm, respectively. The mean water requirement of tomato (variety Arjun) by furrow irrigation schedules at 1.2 IW: CPE method without mulch (which is called as conventional irrigation, treatment T4 in this study) for sandy loam soil in the same study area is earlier reported to be 29.8 cm (Panigrahi**,** 2006) which is close to the present findings of 30.4 cm. Water requirement for the furrow treatment was observed to be maximum because of higher application amount of irrigation water due to the prescribed irrigation schedule. However, drip treatments required less water with a mean value of 25.8, 24.8 and 23.5 cm for 100, 80 and 60% levels of ETc treatments without mulch (treatments T1, T2 and T3, respectively) and with the use of mulch these values for the treatments T5, T6 and T7 were reduced to 24.6, 23.9 and 22.7 cm, respectively (Table 1). There was a saving of 15.13, 18.42 and 22.70% water in drip irrigation (without mulch) for treatments T1, T2 and T3 as compared to conventional furrow irrigation (T4). However, when mulching was done, there was a saving of 19.08, 21.38 and 25.33% water in drip irrigation for treatments T5, T6 and T7, respectively as compared to conventional furrow irrigation (T4). On an average, there was 18.75% reduction in water requirement in the crop when the conventional furrow irrigation method (treatment T4) is substituted by drip with no mulch and with the use of mulch the reduction becomes 21.93%.

The study reveals that furrow irrigation is not a water efficient method of irrigation since, there is undesired percolation loss which no way helps in plant water uptake and hence in the growth and yield of the crop. On an average, there is 5.8 cm percolation loss in case of furrow treatments whereas drip treatments result almost no percolation (Table 1). The reason of occurrence of percolation loss in case of furrow irrigation may be due to higher amount of irrigation (5 cm) applied to the field at a time irrespective of crop growth stage. This makes the irrigation method less efficient and hence uneconomical especially for vegetable crops. Similar conclusions on disadvantages of furrow irrigations have been reported by other authors (Imtiyaz *et al.*, 2000; Panigrahi, 2006; Panigrahi *et al.*, 2011) [13]. Another important finding of the study is that use of mulch decreases the water requirement of crop. Data of Table 1 represents that treatments T5 to T8 (with mulch) requires less water for the crop as compared to treatments T1 to T4 (without mulch) for both the years of study.

Yield and Water-Use-Efficiency

Effect of irrigation schedules and methods on yield and water-use efficiency of tomato under both mulching and non-mulching conditions in both the years along with the mean values is shown in Table 2. The study reveals that in both the years, irrigation schedules including the methods and mulching conditions significantly influence the yield of the crop. In both the years, the highest yield of the crop (18.8 to 19.2 t ha^{-1}) was observed when irrigation during the crop-growing season was performed at 100% ETc replenishment by drip irrigation method with mulch (treatment T5). Even the mean data reveals that significantly highest yield of 19.0 t ha^{-1} is obtained for treatment T5 that is 11.1, 26.7, and 40.6% more than treatments T6, T7 and T8, respectively. Thus the study reveals that the yield of the crop is dependent on both irrigation schedules and methods of irrigation. Comparing to different irrigation schedules in drip method, the treatment T1 is found to require more irrigation water which results in achieving higher values of crop evapotranspiration and thus favouring good growth and yield of the crop. However, when the irrigation methods are compared, it is observed that the drip irrigation gives more yield than the furrow method. In case of furrow irrigation, though more water is applied to the crop, yet the water uptake by the crop is not efficient and there are some unnecessary losses of the applied water in the form of deep percolation. This is the reason why yield is not commensurate with the water requirement of the crop indicating the response of the crop on irrigation methods.

Table 1: Irrigation and water requirement of tomato as influenced by different treatments

Year	Treatment	Irrigation requirement (cm)	Effective rain (cm)	Soil moisture contribution (cm)	Deep percolation (cm)	Water requirement (cm)
2012	T1	24.0	3.0	-1.5	0	25.5
	T2	20.2	3.0	1.0	0	24.2
	T3	17.2	3.0	2.8	0	23.0
	T4	30.0	3.0	-2.6	6.1	30.4
	T5	24.0	3.0	-2.9	0	24.1
	T6	20.2	3.0	0.4	0	23.6
	T7	17.2	3.0	1.9	0	22.1
	T8	30.0	3.0	-3.8	5.9	29.0
2013	T1	24.8	2.8	-1.4	0.4	26.2
	T2	20.8	2.8	1.7	0	25.3
	T3	18.0	2.8	3.2	0	24.0
	T4	30.6	2.8	-2.9	5.5	30.5
	T5	24.8	2.8	-2.6	0.5	25.0
	T6	20.8	2.8	0.6	0	24.2
	T7	18.0	2.8	2.4	0	23.2
	T8	30.6	2.8	-4.0	5.4	29.4
Mean	T1	24.4	2.9	-1.5	0.2	25.8
	T2	20.5	2.9	1.4	0	24.8
	T3	17.6	2.9	3.0	0	23.5
	T4	30.3	2.9	-2.8	5.8	30.4
	T5	24.4	2.9	-2.7	0.3	24.6
	T6	20.5	2.9	0.5	0	23.9
	T7	17.6	2.9	2.2	0	22.7
	T8	30.3	2.9	-3.9	5.7	29.3

Table 2: Effects of treatments on yield, water requirement (WR) and water-use efficiency (WUE) of tomato

Treatment	2012			2013			Mean		
	Yield, t ha^{-1}	WR, cm	WUE, t ha^{-1} cm^{-1}	Yield, t ha^{-1}	WR, cm	WUE, t ha^{-1} cm^{-1}	Yield, t ha^{-1}	WR, cm	WUE, t ha^{-1} cm^{-1}
T1	16.5	25.5	0.647	17.5	26.2	0.668	17.0	25.8	0.659
T2	15.0	24.2	0.620	16.6	25.3	0.656	15.5	24.8	0.625
T3	13.5	23.0	0.587	14.1	24.0	0.588	13.8	23.5	0.587
T4	12.0	30.4	0.395	12.8	30.5	0.420	12.4	30.4	0.408
T5	18.8	24.1	0.780	19.2	25.0	0.768	19.0	24.6	0.772
T6	16.8	23.6	0.711	17.4	24.2	0.719	17.1	23.9	0.715
T7	14.7	22.1	0.665	15.3	23.2	0.659	15.0	22.7	0.661
T8	12.5	29.0	0.431	13.0	29.4	0.442	12.8	29.3	0.437
SEm (±)	0.426	0.13	0.233	0.456	0.12	0.253	0.448	0.11	0.245
CD(0.05)	1.293	0.35	0.454	1.312	0.33	0.471	1.304	0.30	0.466

Another important finding of the study is that mulching has a positive effect on enhancing yield and water-use efficiency (WUE) of the crop. Data of Table 2 indicates that yield of tomato is more under mulching than un-mulched condition. Mean yield of the crop under conventional furrow irrigation (T4) is found to be 12.4 t ha^{-1} which is 3.22% less when the same treatment is imposed with incorporation of mulch (treatment T8). It is observed that when the crop is grown under treatment T5, there is 53.2% yield increase than when it is grown under conventional furrow method. Irrespective of irrigation methods and irrigation schedules, it is noted that the yield of the crop is 8.82% more when only mulching is considered. Beneficial effect of mulching on yield increase may be due to maintaining higher soil moisture status in the root zone of the crop. Paul *et al.* (2013) [20] have also reported the highest yield (28.7 t ha^{-1}) of capsicum which was recorded under 100% ETc replenishment with drip irrigation and plastic mulch condition as compared to other treatments.

There was significant increase in water-use efficiency (WUE) in response to drip irrigation treatments at all the levels of irrigation schedules in comparison to furrow irrigation in both the years. Values of WUE for treatment T5 is found to be the highest varying from 0.768 to 0.780 t ha^{-1} cm^{-1} over the years with a mean value of 0.772 t ha^{-1} cm^{-1} where as the mean values of WUE for treatments T6, T7 and T8 are 0.715, 0.661 and 0.437 t ha^{-1} cm^{-1}, respectively (Table 2). The values of WUE decreased significantly with decrease of irrigation water supply due to 80 and 60% ETc replenishment. The study reveals that there is significantly 5.4, 12.3 and 61.5% increase in values of WUE of the crop when treatment T1 is imposed over treatments T2, T3 and T4, respectively. However, when mulching is done, the respective treatments produce more yields. For example, treatment T5 produces 8.0% more yield as compared to treatment T6, 16.8% more over T7 and 76.7% more over T8. Irrigation by furrow method produces the lowest value of WUE because it requires more seasonal water application without a significant improvement in yield of the crop. Similar conclusions have been reported by earlier studies (Anonymous, 2004; Tiwari *et al.*, 1998) [24] for various crops like, tomato, potato, carrot etc. in which furrow method of irrigation has been compared with drip irrigation systems. Thus the study reveals that the drip irrigation at 100% ETc level with mulching (treatment T5) has significant influence on fruit yield and WUE over any other treatments and produces significantly highest value of WUE of 89.2% over the conventional furrow irrigation method (treatment T4).

Conclusions

The study revealed that there was 20.0 to 42.7% savings of irrigation water in various drip treatments as compared to furrow treatment. Drip irrigation at 100% ETc replenishment with black plastic mulch resulted in significantly mean highest yield of 19.0 t ha^{-1} of the crop that is 11.1, 26.7 and 48.4% more than drip irrigation at 80 and 60% ETc replenishment with mulch and furrow irrigation with mulch, respectively. There is a significant yield increase of 53.2% when the crop is grown with drip irrigation at 100% ETc replenishment with black plastic mulch as compared to the conventional furrow irrigation. Furthermore the said treatment also gives significantly highest water-use efficiency of 0.772 t ha^{-1} cm^{-1} which is 89.2% over the conventional furrow irrigation treatment. Thus, the overall results suggests that in order to obtain high yield and water-use efficiency of tomato in sub-humid climatic condition of Odisha, India, the crop during the winter season should be irrigated by drip irrigation at 100% ETc replenishment with incorporation of black plastic mulch.

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