Water use and yield response of tomato as influenced by drip and furrow irrigation

B. Panigrahi[1], D.P. Roy[2], S. N. Panda[3]

(1. *Orissa University of Agriculture and Technology*, *Bhubaneswar*-751003, *Orissa*, India;

2. *Department of Agriculture and Food Engineering*, *Indian Institute of Technology*, *Kharagpur*, 721 302, *India*)

Abstract: Field experiments were conducted for three years (2002, 2003 and 2004) on sandy loam soil at the Regional Research and Technology Transfer Station, Chiplima, Orissa, India to study the effects of furrow irrigation and variable water supply by drip irrigation on yield and water use of tomato crop. The study was conducted in randomized block design with four treatments having five replications each. The treatments were (i) T_1 = drip irrigation at 100% crop evapotranspiration (ET_c) replenishment, (ii) T_2 = drip irrigation at 80% ET_c replenishment, (iii) T_3 = drip irrigation at 60% ET_c replenishment and (iv) T_4 = furrow irrigation at 1.2 IW: CPE (IW = irrigation water of depth 5 cm and CPE = cumulative pan evaporation). Tomato variety Arjun was planted in all the treatments with 90 cm spacing from row to row and 75 cm spacing from plant to plant. In drip irrigation, crops were irrigated at 2-day intervals. Studies on soil moisture distribution revealed that the vertical movement of soil moisture was higher than the horizontal one for different time intervals after application of irrigation for all the drip treatments. However, the moisture distribution pattern indicated that there was maximum extraction of soil moisture from 15-30 cm depth that resulted in obtaining higher values of ET_c for said profile layer than for all other layers for all the treatments. Treatment T_1 was observed to maintain higher values of moisture content both horizontally and vertically throughout the crop growth period than all other treatments. Because of this reason, the yield of crop was found to be maximal (180.97 q/ha) for the treatment T_1 (drip irrigation at 100% ET_c replenishment) whereas those for treatments T_2, T_3 and T_4 were 162.77, 145.12 and 156.86 q/ha, respectively. The study reveals that drip irrigation at 100% ET_c replenishment in tomato can increase the yield by 15.4%, besides saving 17.9% more costly irrigation water than the conventional furrow irrigation practiced by most of the farmers.

Keywords: drip, furrow, irrigation schedule, evapotranspiration, treatment, moisture content

Citation: Panigrahi B., D.P. Roy, and S. N. Panda. 2010. Water use and yeld response of tomato as influenced by drip and furrow irrigation. International Agricultural Engineering Journal, 19(1): 19－30.

1 Introduction

Water is the most limiting natural resource hindering the economic development of any developing country, including India. India is blessed with abundant water resources; however, due to various physiographic constraints, legal constraints and the present method of utilization, the utilizable water for irrigation is being exhausted. Further, the increasing demand of water for expanding urbanization and industrialization will make the situation more critical because the share of water designated 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. Improper irrigation management practices not only waste scarce and expensive water resources but

Received date: 2009-09-12 **Accepted date:** 2010-05-20

Biographies: B. Panigrahi, Professor and Vice Chancellor. **D.P. Roy,** Professor and Vice Chancellor, Orissa University of Agriculture & Technology, Bhubaneswar-751003, Orissa, India. **S.N. Panda,** Professor, Department of Agriculture & Food Engineering, Indian Institute of Technology, Kharagpur, India-721 302

Corresponding author, Professor, Orissa University of Agriculture & Technology, Bhubaneswar-751003, Orissa, India. Email: kajal_bp@yahoo.co.in

also decrease crop yield (Imtiyaz et al. 2000; Tiwari et al, 1998). In the present-day context, improvement in irrigation practices, including schedules and methods, is needed to increase crop production and to sustain productivity levels.

Furrow irrigation is the conventional method widely used to irrigate most of the vegetable crops grown in Orissa, India. However, this method uses more water compared to other high-tech water-saving irrigation methods such as sprinkler, drip etc. Many researchers have reported the higher application efficiency of drip irrigation systems over the conventional furrow irrigation systems (Tiwari et al., 1998; Bhandari, 1995; Hanson et al., 1997; Fekadu and Teshome, 1998). Sivanappan and Padmakumari (1980) compared drip and furrow irrigation systems in vegetables and found that there was savings of 67% to 80% more irrigation water than surface irrigation methods. Based on a study conducted at Rahuri, India, Khade (1987) reported 60% higher yield of okra with water savings of 40% under drip irrigation as compared to furrow irrigation. Tiwari et al. (1998) 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.

In drip irrigation systems, water in small amounts but at frequent intervals is applied to the crop. Generally, water is applied in the root zone of the crop, because of which the surface runoff and deep percolation below the effective root zone are avoided. This increases application efficiency, making the system more water-efficient. The distribution of moisture in the root zone is basically influenced by the type of the soil, discharge rate of the emitter and duration of irrigation. Efficiency of water application depends on the hydraulics of the moisture advancement pattern under the drip emitter. The flow phenomenon in a drip irrigation system can be analyzed on the basis of moisture spread in an unsaturated zone from a point source of water application (Bhandari, 1995).

Tomato is an important vegetable crop grown in almost all parts of India and is one of the most preferred vegetable crops in Orissa (eastern state of India). Due to lack of information on irrigation management techniques, the average yield of the crop in Orissa 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 becoming interested in growing the crop with drip irrigation. The government is also offering financial assistance to farmers who use this technique, especially for fruit and vegetable crops. However, some farmers in the state are reluctant to adopt drip technology due to lack of information on irrigation scheduling techniques. Also, not much information on seasonal water requirements of tomato by drip irrigation is available. Hence, the present study was undertaken to examine the soil moisture distribution pattern under different irrigation schedules by drip irrigation and suggest the most efficient irrigation schedule that would attain the highest yield and water-use efficiency of the crop. Another objective of the study was to find out the water requirement and yield of the crop grown by the conventional furrow irrigation method, which is now practiced by the farmers in the region, and compare it with that grown by the drip system.

2 Materials and method

Field experiments were conducted at the Regional Research and Technology Transfer Station in Chiplima, Orissa, India for three consecutive years in winters 2002, 2003 and 2004 to study the soil moisture distribution pattern and ultimately its impacts on yield and water use efficiency of tomato crop which was irrigated by drip as well as furrow irrigation methods. The latitude, longitude and altitude of the study area are 20°21′N. 80°55′E and 178.8 m above mean sea level, respectively. The area falls under the sub-humid climatic condition in the eastern part of the country. The total rainfall in the study area during crop growing season (8th January to 3rd April) was 32.0 mm, 29.0 mm, and 38.0 mm in 2002, 2003 and 2004, respectively. The mean daily air temperature during the study period ranged from 15.4℃ to 30.3℃, 16.8℃ to 29.9℃ and 16.1℃ to 30.5℃, and mean daily relative humidity raged from 42.5% to 68.7%, 45.2% to 70.3%, and 44.4% to 71.7% in 2002, 2003 and

2004, respectively.

The 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 1.52 gm/cm^3, 26 %, 10 %, and 10 mm/h, respectively. Average pH, EC, and organic carbon were 6.3, 0.09 dS/m, and 0.513%, respectively.

The experimental technique followed four treatments having five replications each, and the design followed was randomised block design. The four treatments were (i) T_1 = drip irrigation at 100% crop evapotranspiration (ET_c) replenishment, (ii) T_2 = drip irrigation at 80% ET_c replenishment (iii) T_3 = drip irrigation at 60% ET_c replenishment and (iv) T_4 = furrow irrigation at 1.2 IW: CPE (IW = irrigation water of depth 5 cm and CPE = cumulative pan evaporation). Irrigation scheduling based on the ratio of irrigation water to cumulative pan evaporation (IW: CPE) is one of the simplest methods for which no sophisticated instrument is required. Only a class A pan evaporimeter is required to find out daily pan evaporation value, and for any chosen IW: CPE value, 5 cm irrigation is applied irrespective of plant growth stage when the desired cumulative pan evaporation (CPE) value is reached. Because of its simplicity in use, farmers of India popularly adopt the method, and therefore it is the recommendation of the Directorate of All India Co-ordinate Projects for Research on Water Management and various State Agricultural Universities to use the IW: CPE approach for irrigation scheduling of various crops, including tomato. Earlier studies were undertaken by many authors to find out the water requirement of tomato by the IW: CPE approach (Cripps George, and Oakley, 1982, Singh, Joshi, and Singh., 1988). 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 a control to compare the water requirement and water-use efficiency of tomato by drip and furrow irrigation systems.

Tomato variety Arjun was planted in all the treatments with 90 cm spacing from row to row and 75 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 the case of drip irrigation, lateral spacing of the drip laterals were 1.8 m and emitter/dripper spacing was 0.75 m. There were two crop rows per each lateral and one emitter/dripper per plant. Figure 1 represents the layout plan of the drip irrigation system. Figure 2 represents the individual plot-drip system design along with the planting geometry. The net plot area of all treatments was 5.5 m×4.5 m. Buffer spaces of 1 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 HP submersible pump.

The furrows had dikes at the downstream end to prevent runoff. Polyethylene sheeting 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 each year.

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 whereas top dressing fertilizer was applied as ring placement in all drip and furrow treatments.

Drip irrigation was scheduled once in two days based on the two previous days' crop evapotranspiration data at 100, 80 and 60% level. Irrigation water applied by drip to each plant every two days (V) was computed as (Anonymous, 2002):

$$V = \text{Two days } CPE \times Kp \times Kc \times A \times Wp \quad (1)$$

Where: V is volume of water in lit; CPE is cumulative pan evaporation, mm; Kp is pan coefficient; Kc is crop coefficient; A is area around each plant served by the emitter for irrigation, m^2; and *Wp* is wetted percentage.

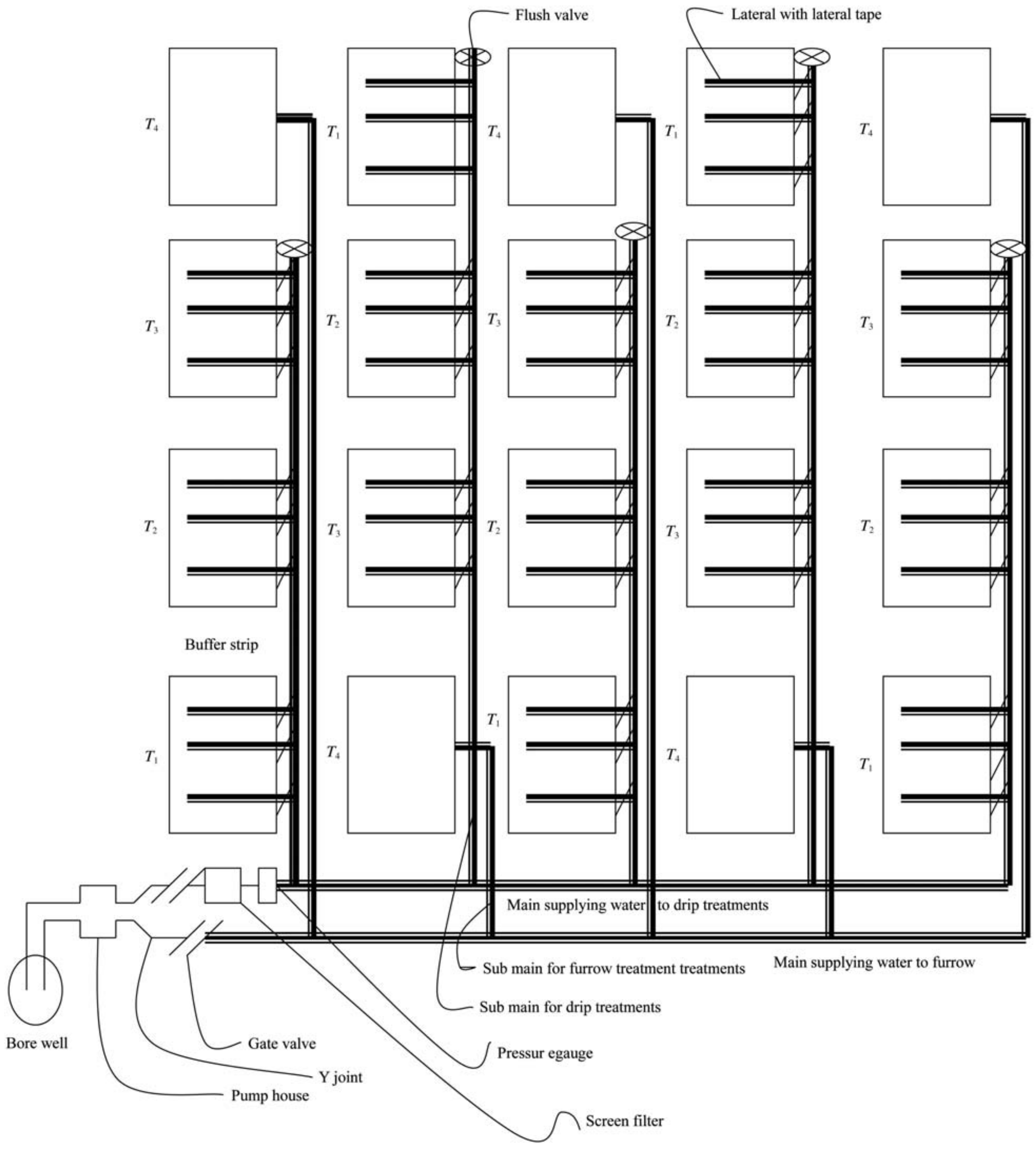


Figure 1 Layout plan of experimental setup

Value of *Kp* for the study area was assumed as 0.8 (Michael, 1981). Based on the field experiment, the values of *Kc* of tomato for crop establishment, crop development, mid season and maturity stages were taken as 0.45, 0.75, 1.10 and 0.65, respectively. The value *Wp* was assumed as 0.5 during crop establishment stage and 0.75 during other stages (Anonymous, 2002). Since, during the establishment stage, crop coverage was smaller, requiring less irrigation, *Wp* was assumed as a low value (0.5) compared to other stages. The area around each plant served by the emitter for irrigation was estimated as $A = 0.90 \times 0.75 = 0.675$ m^2.

Operating duration of each emitter was estimated as:

Operating duration = V / (Number of emitters/plant x emitter discharge rate) (2)

Where: operating duration is in hours, V is volume in lit and emitter discharge rate is in L/h.

Volume of irrigation water and hence the operating duration of 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--100%, 80% and 60% level). In the experiment, the number of emitters per plant was kept at 1 and the emitter discharge rate, which was 3 L/h, was kept fixed for all treatments.

2.1 Design and layout of drip system

The design and layout plan of the drip irrigation system is shown in Figure 1. From the water source (bore well), the irrigation water was pumped with a submersible 1 HP pump and was supplied to the plots through a PVC main pipe (63 mm diameter) fitted with a gate valve. Water was supplied to the drip treatments through the 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 1.8 m apart. Drippers/emitters were connected to laterals through small-size inbuilt PVC pipes. Laterals were laid at the center of two rows and there was one emitter/dripper per plant (Figure 2). Flush valves were provided at the end of sub-mains. Lateral tapes (12 mm) 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 3 L/h. There were 12 emitters per lateral and so the total discharge rate of each lateral was 36 L/h. There were nine laterals connected to each sub-main, and the discharge rate of each sub-main was 324 L/h. The discharge rate of each main line having five sub-mains was 1,620 L/h. Water was supplied to furrow treatments through separate mains and sub-mains of the same size PVC pipes along with gate and flush valve as used in drip system. A Y joint with rubber tubes connected at one end to the delivery pipe of the pump and the other two ends connected to the main pipes used to deliver irrigation to the drip and furrow treatments was used in the experiment (Figure 1). Further, a Parshall flume was used to measure the irrigation water supplied to all plots in the furrow treatments.

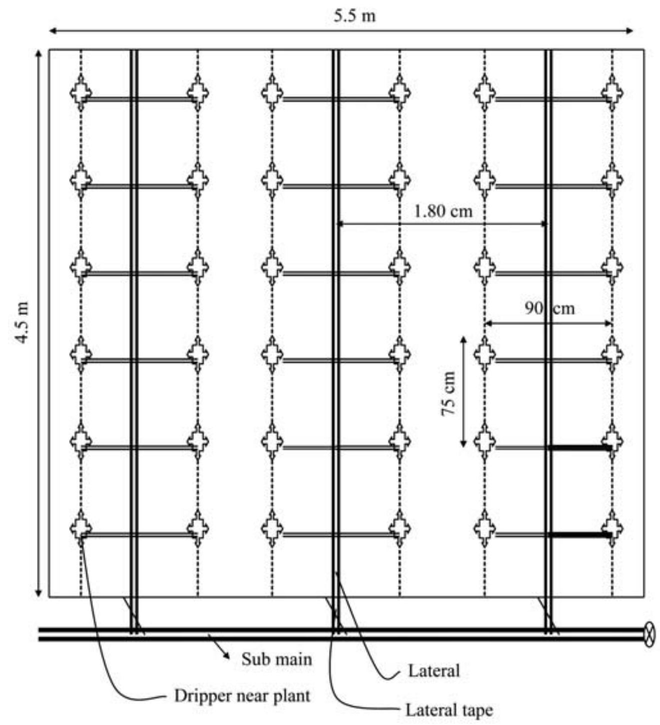


Figure 2 Individual plot-Drip system design and planting geometry in tomato

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 (ET_c) was estimated (Ahmed and Mishra, 1987) as follows:

$$ET_c = P - R + I_r \pm \Delta S - D \quad (3)$$

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 because the 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 all the three years of the experiments, average seasonal rainfall during the crop growth period was only 3.3 cm. There was no day having rainfall more than even 1 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) as:

$$D = K_\theta \delta h / \delta z \tag{4}$$

Where: D is deep percolation, mm/d; $\delta h/\delta z$ is water potential gradient between 60 cm and 75 cm depth below soil surface; and K_θ is unsaturated hydraulic conductivity, mm/d; which is a function of volumetric soil moisture, θ.

During the crop growing period, gravimetric soil moisture contents on percent 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. These values were converted to percent volumetric basis (θ) by multiplying the respective values with bulk density of soil of each 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 the 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). Tensiometers were placed at 60 cm and 75 cm depths in each plot for determination of water potential gradient.

The moisture distribution patterns for drip irrigated plots were also studied by recording moisture content at different depths and at different radial distance around the emitter/plant over three hours at 30 minute intervals. Data on crop yield was recorded for all treatments. Water-use efficiency (WUE) of the crop for each treatment was computed from yield and water requirement data.

3 Results and discussion

3.1 Irrigation requirement and water use

Water requirement including irrigation requirement of the crop for all the treatments in all three 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 all years. The irrigation requirement in the case of furrow treatments was found to range from 25 to 30 cm in different years, with a mean value of 26.8 cm. In case of drip irrigation, the treatment with 100% ET_c was observed to require the highest irrigation (irrigation ranging from 20.0 to 24.4 cm) whereas the treatment with 60% ET_c was found to require the lowest irrigation (ranging from 16.3 to 17.4 cm) in all the three years. The mean irrigation requirements of drip treatments with 100, 80 and 60% levels of ET_c were obtained as 22.0, 19.2 and 17.0 cm, respectively (Table 1). Irrigation requirement for 100% levels of ET_c treatment was observed to be the higher than all other drip treatments because more irrigation water was required by the plant at this level. Total mean seasonal irrigation requirement of crop at 100% levels of ET_c was 29.4% more than that at 60% level of ET_c and 14.6% more than that at 80% level of ET_c. However, compared to the furrow treatment, all the drip treatments needed less irrigation; mean seasonal values of savings of irrigation water in drip treatments ranged from 17.9% to 36.6% as compared to furrow treatment.

Table 1 Irrigation and water requirement of tomato as influenced by irrigation schedules and methods

Year	Irrigation		Irrigation requirement /cm	Effective rain /cm	Soil moisture contribution /cm	Deep percolation /cm	Water requirement /cm
	Methods	Schedules					
2002	Drip	100% ET_c	24.4	3.2	-2.0	0	25.6
		80% ET_c	20.0	3.2	1.3	0	24.5
		60% ET_c	17.4	3.2	3.0	0	23.6
	Furrow	1.2 IW:CPE	30.0	3.2	-3.5	4.4	29.7
2003	Drip	100% ET_c	21.6	2.9	-0.7	0.3	23.8
		80% ET_c	19.3	2.9	0.4	0	22.6
		60% ET_c	17.2	2.9	1.8	0	21.9
	Furrow	1.2 IW:CPE	25.0	2.9	-2.2	3.8	26.5

2004	Drip	100% ET_c	20.0	3.8	-0.4	0	23.4
		80% ET_c	18.3	3.8	0.2	0	22.3
		60% ET_c	16.3	3.8	0.9	0	21.0
	Furrow	1.2 IW:CPE	25.0	3.8	-1.8	4.1	27.0
Mean	Drip	100% ET_c	22.0	3.3	-1.0	0.1	24.3
		80% ET_c	19.2	3.3	0.6	0	23.1
		60% ET_c	17.0	3.3	1.9	0	22.2
	Furrow	1.2 IW:CPE	26.8	3.3	-2.4	4.1	27.7

The water requirement of the crop with the furrow treatment was also found to be highest compared to any drip treatments in all three years of study. The water requirement for the furrow treatment was found to range from 26.5 to 29.7 cm with a mean value of 27.7 cm. The mean water requirement of tomato (variety Arjun) by furrow irrigation schedules at 1.2 IW: CPE method for sandy loam soil in the same study area was earlier reported to be 28.4 cm (Panigrahi**,** 2006). Water requirement for the furrow treatment was observed to be maximal because of higher need of irrigation water. However, drip treatments required less water, with mean values of 24.3, 23.1 and 22.2 cm for 100%, 80% and 60% levels of ET_c treatments, respectively (Table 2). There was a significant saving of 20% water in drip irrigation with 60% level of ET_c as compared to conventional furrow irrigation. On average, there was 16.2% reduction in water requirement in the crop when the furrow irrigation method was substituted by drip.

Table 2 Water requirement of tomato as affected by irrigation schedules and methods (pooled over 2002, 2003 and 2004) with statistical test parameters

Irrigation		Water requirement /cm	Statistical parameters
Methods	Schedules		
Drip	100% ET_c	24.3	$SE_m(\pm) = 0.11$
	80% ET_c	23.1	CD (0.05) = 0.30
	60% ET_c	22.2	C.V. = 3.51%
Furrow	1.2 IW: CPE	27.7	

The study reveals that furrow irrigation is not a water efficient method of irrigation because there is undesired percolation loss which in no way helps in plant water uptake and hence in the growth and yield of the crop. On an average, there is 4.1 cm percolation loss in the case of furrow treatments, whereas drip treatments result in no percolation (Table 1). The occurrence of percolation loss in the case of furrow irrigation may be due to a higher amount of irrigation (5 cm) applied to the field at one 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 irrigation have been reported by other authors (Imtiyaz et al., 2000, Panigrahi, 2006).

3.2 Seasonal crop evapotranspiration

Seasonal crop evapotranspiration (ET_c) of tomato is found to range from 4.0 to 8.0 cm, 3.6 to 7.7 cm, 3.5 cm to 7.3 cm and 4.2 cm to 7.6 cm for drip irrigation at 100%, 80% and 60% level of ET_c and furrow irrigation, respectively, for various soil profile layers (Table 3). The extraction of soil moisture for different treatments is found to be at maximum for profile layer of 15-30 cm, indicating that root density is highest in this layer compared to other layers, because of which plants uptake more soil moisture, resulting higher values of ET_c. The study also reveals that drip treatment with 100% ET_c level gives higher values of seasonal ET_c for all the profile layers compared to all other treatments. The mean seasonal ET_c value of tomato for drip with 100% ET_c level was 24.2 cm, which is the highest amongst all the drip treatments and even 2.5% more than the furrow treatment (Table 3). The reason for obtaining higher ET_c values for drip treatments may be due to low but frequent irrigation, which avoids percolation and runoff losses but meets the water uptake demand of the crop in due time.

Variation of soil moisture in terms of lateral and vertical movement below the drip emitters as well as at different radial distances from the drip emmiters after 30, 60, 120 and 180 min of termination of irrigation for treatments T_1, T_2 and T_3 is presented in Figures 3, 4 and 5, respectively. It was observed that the soil moisture contour lines are denser for drip with 100% level of ET_c treatments than for all other drip treatments, indicating that the plant water uptake is maximal for this treatment. The vertical movement of soil moisture was found to be higher than the horizontal one for different time intervals after application of irrigation for all the drip treatments. However, the moisture distribution pattern indicates that there is more extraction of soil moisture from 15-30 cm depth than from all other profile depths. This has resulted in obtaining higher values of ET_c for the 15-30 cm profile layers than all other layers for all the treatments (Table 3).

Table 3 Mean seasonal actual evapotranspiration (ET_c) of tomato as related to different soil profile layers

Irrigation		Soil profile layers/cm				Total seasonal ET_c /cm
Methods	Schedules	0-15	15-30	30-45	45-60	
Drip	100% ET_c	5.9	8.0	6.3	4.0	24.2
	80% ET_c	5.7	7.7	6.1	3.6	23.1
	60% ET_c	5.4	7.3	6.0	3.5	22.2
Furrow	1.2 IW: CPE	5.8	7.6	6.0	4.2	23.6

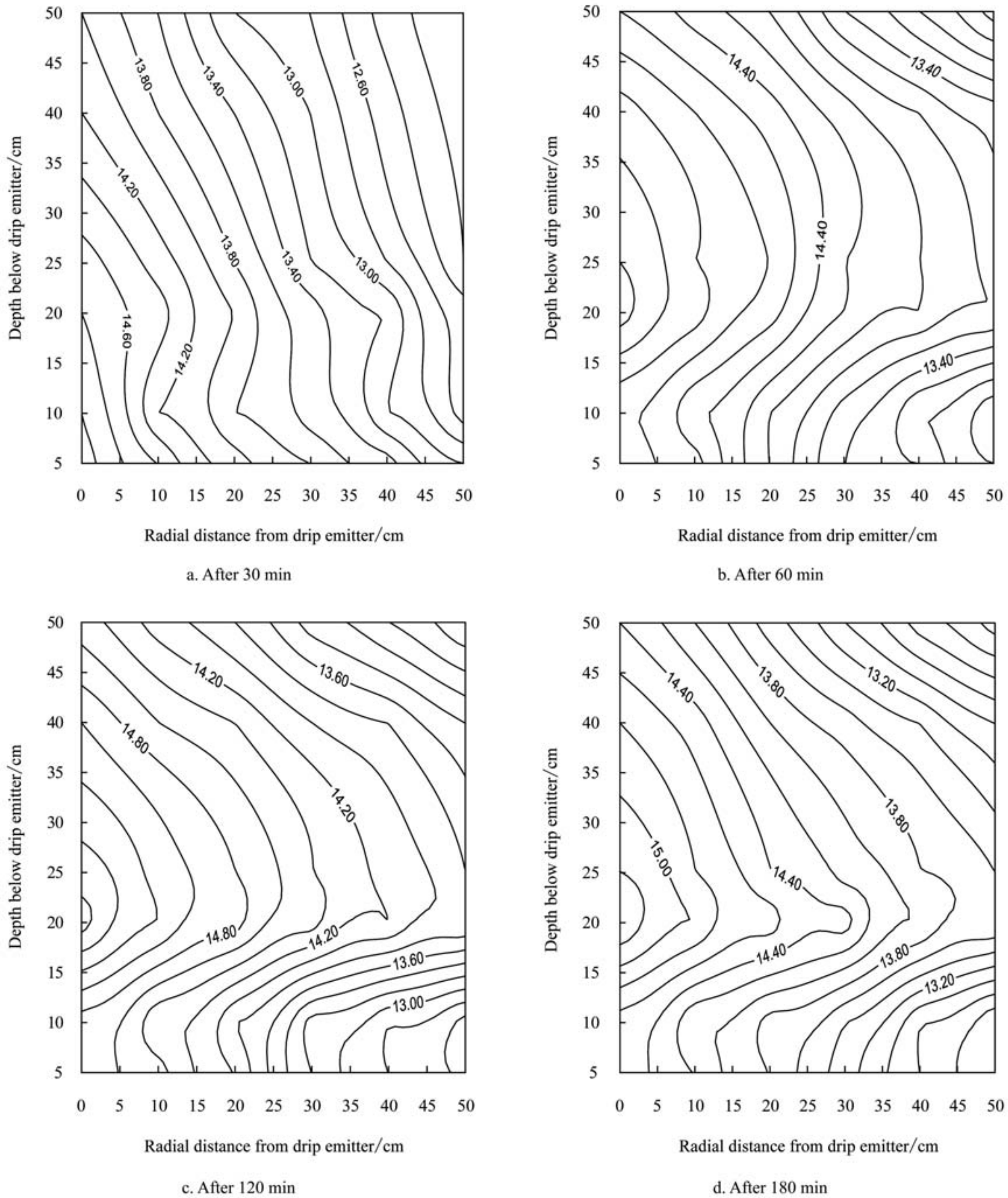


Figure 3 Soil moisture distribution for 100% ET_c drip treatment: after 30 min, 60 min, 120 min amd 180 min. of termination of irrigation

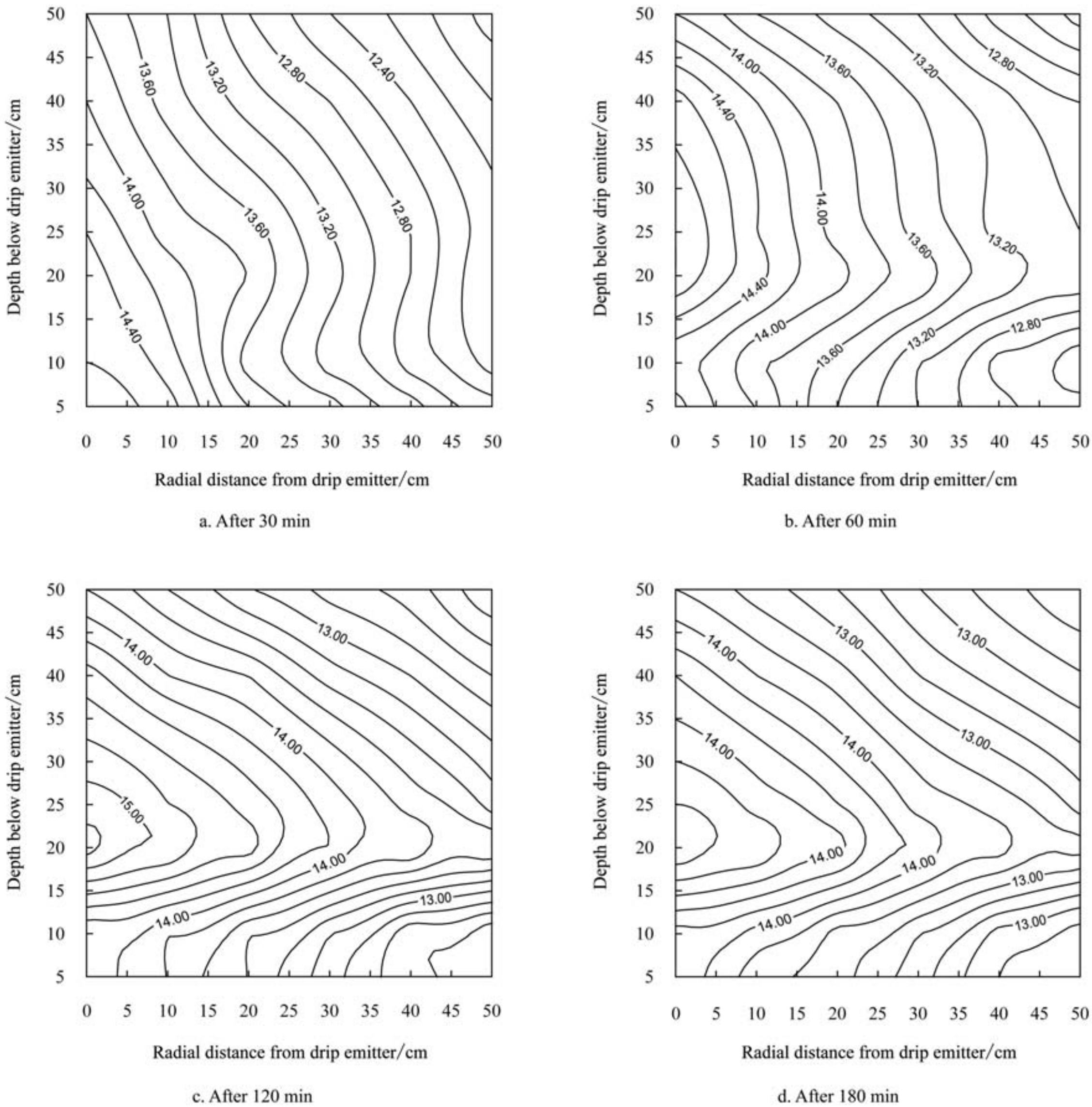
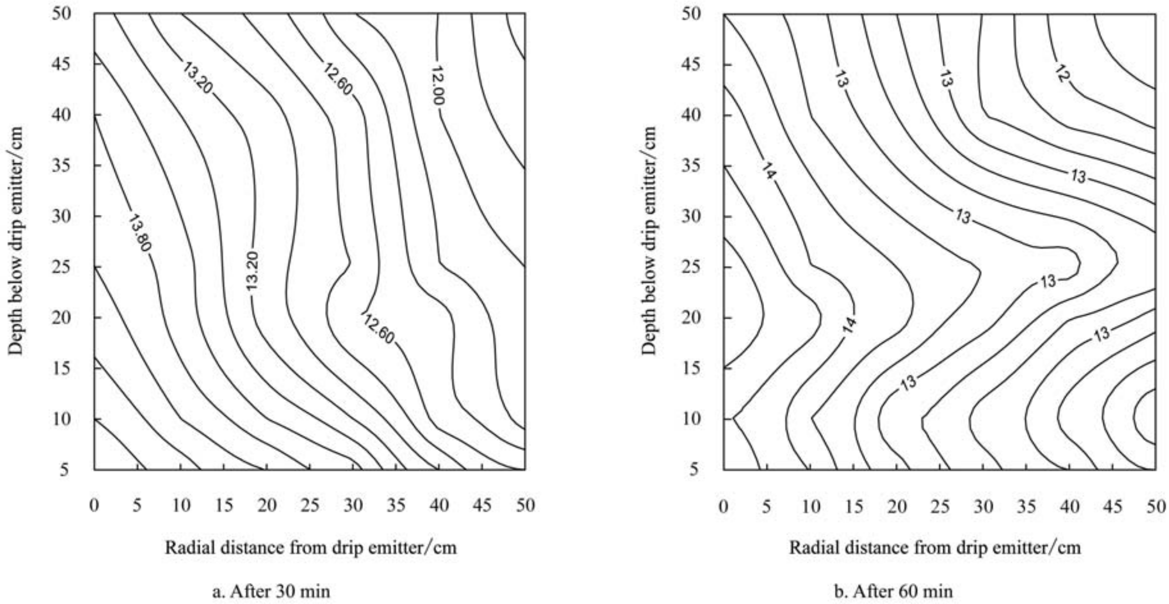
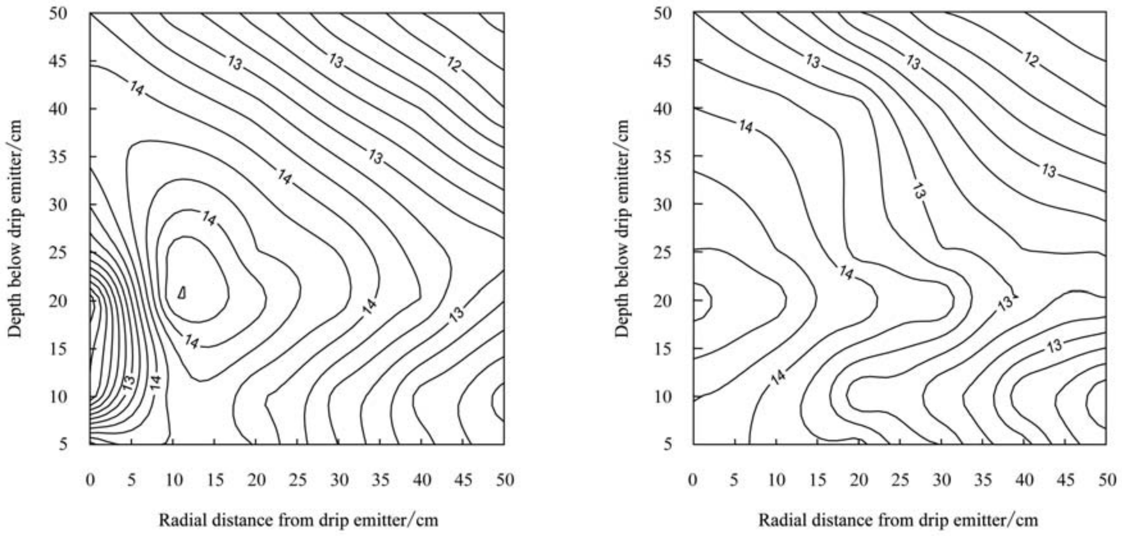


Figure 4 Soil moisture distribution for 80% ET_c drip treatment: after 30 min, 60 min, 120 min and 180 min of termination of irrigation





c. After 120 min d. After 180 min

Figure 5 Soil moisture distribution for 60% ET_c drip treatment: after 30 min, 60 min, 120 min and 180 min of termination of irrigation

3.3 Effect of irrigation treatments on yield and water-use-efficiency

Effects of irrigation schedules and methods on yield and water-use efficiency of tomato in different years along with the mean values are shown in Table 4. The study reveals that in all years, irrigation schedules and methods significantly influenced the yield of the crop. In all years, the highest yield of the crop (173.46 to 191.36 q/ha) was observed when irrigation during the crop-growing season was performed at 100% ET_c replenishment by drip irrigation method (T_1). Even the mean data reveals that the highest yield of 180.97 q/ha is obtained for treatment T_1; that is, 11.2%, 24.7%, and 15.4% more than treatments T_2, T_3 and T_4, respectively. Yield of the crop is found to depend on both irrigation schedules and methods of irrigation. Compared to different irrigation schedules in the drip method, the treatment T_1 is found to require more irrigation water, which results in achieving higher values of crop evapotranspiration, thus favouring good growth and yield of the crop. However, when the irrigation methods are compared, it is observed that drip irrigation (except treatment T_3) gives more yield than the furrow method. In case of furrow irrigation, although more water is applied to the crop, 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 to irrigation methods.

Table 4 Effect of irrigation schedules and methods on tomato yield and water-use efficiency along with statistical parameters

Year	Irrigation		Yield /q • ha^{-1}	Water-use efficiency /kg • ha^{-1} cm
	Methods	Schedules		
2002	Drip	100% ET_c	178.10^a	695.70
		80% ET_c	160.55^b	655.31
		60% ET_c	148.34^c	628.56
	Furrow	1.2 IW: CPE	155.61^d	523.94
	$SE_m(\pm)$		2.85	5.55
	CD (0.05)		7.48	10.12
	C.V. (%)		5.14	8.10
2003	Drip	100% ET_c	191.36	804.03
		80% ET_c	171.60	759.29
		60% ET_c	151.23	690.55
	Furrow	1.2 IW: CPE	163.12	615.55
	$SE_m(\pm)$		2.03	4.78
	CD (0.05)		7.04	9.65
	C.V. (%)		5.96	7.66
2004	Drip	100% ET_c	173.46	741.28
		80% ET_c	156.17	700.31
		60% ET_c	135.80	646.67
	Furrow	1.2 IW: CPE	151.85	562.41
	$SE_m(\pm)$		3.27	5.16
	CD (0.05)		10.80	9.05
	C.V. (%)		4.80	8.33
Mean of three years	Drip	100% ET_c	180.97	744.73
		80% ET_c	162.77	704.63
		60% ET_c	145.12	653.69
	Furrow	1.2 IW: CPE	156.86	566.28
	$SE_m(\pm)^{a1}$		3.05	5.02
	CD (0.05)^{b1}		8.92	9.60
	C.V. (%)^{c1}		5.10	7.85

N.B. a1 = standard error (SE) between the mean values (mean of 3 years) among the treatments; b1=Coefficient of deviation (CD) showing significant differences between the mean values among the treatments; c1 = Coefficient of variation (CV) between the mean values among the 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 all the years. Values of *WUE* for treatment T_1 are found to be the highest, varying from 695.70 to 804.03 kg/ha cm over the years with a mean value of 744.73 kg/ha, whereas the mean values of WUE for treatments T_2, T_3 and T_4 are 704.63, 653.69 and 566.28 kg/ha cm, respectively (Table 4). The values of *WUE* decreased significantly with decrease of irrigation water supply due to 80% and 60% ET_c replenishment. The study reveals that there is 5.7%, 13.9% and 27.3% increase in values of *WUE* of the crop when treatment T_1 is imposed over treatments T_2, T_3 and T_4, respectively. Furthermore, irrigation by the furrow method produces the lowest value of *WUE* because it requires considerable 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, Bhandari, 1995) for various crops, such as tomato, potato, carrot, etc., in which the furrow method of irrigation has been compared with drip irrigation systems. Thus the study reveals that drip irrigation at 100% ET_c level has significant influence on fruit yield and water-use efficiency compared to the two other irrigation schedules under drip (i.e., 80% and 60% ET_c level), and also over the conventional furrow irrigation method.

4 Conclusions

The experimental results from all the three years showed that furrow irrigation is not a water saving method of irrigation in tomato. The conventional furrow irrigation as adopted by most of the farmers increases the seasonal water application considerably without a significant improvement in yield and hence in water-use efficiency. On the other hand, drip irrigation supplied low-amount but frequent irrigation that maintained higher values of soil moisture in the root zone and hence resulted in higher yield and water-use efficiency. The study revealed that there was 17.9% to 36.6% savings of irrigation water in various drip treatments as compared to furrow treatment. Drip irrigation at 100% ET_c replenishment resulted in significantly higher yield of the crop at 180.97 q/ha; that is, 11.2%, 24.7%, and 15.4% more than drip irrigation at 80% and 60% ET_c replenishment and furrow irrigation treatments, respectively. Furthermore, said treatment also increased the water-use efficiency by 5.7%, 13.9% and 27.3% over the treatments of drip irrigation at 80% and 60% ET_c replenishment and furrow irrigation treatments, respectively. Thus, the overall results suggest that in order to obtain optimum yield and water-use efficiency of tomato in the sub-humid climatic condition of Orissa, India, the crop during the winter season should be irrigated by drip irrigation at 100% ET_c replenishment.

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