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Fertigation studies and irrigation scheduling in drip irrigation system in tomato crop (*Lycopersicon esculentum* L.)

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Abstract

Response to urea fertilizer with drip irrigation was tested and compared with conventional furrow irrigation for 2 years (1995 and 1996) at the Research Farm of Water Management Project, Mahatma Phule Agricultural University, Rahuri (Maharashtra), India. Application of nitrogen through the drip irrigation in ten equal splits at 8-days interval saved 20–40% nitrogen as compared to the furrow irrigation when nitrogen was applied in two equal splits (at planting and 1 month thereafter). Similarly, 3.7–12.5% higher fruit yield with 31–37% saving of water was obtained in the drip system. Water use efficiency in drip irrigation, on an average over nitrogen level was 68 and 77% higher over surface irrigation in 1995 and 1996, respectively. At 120 kgN ha^{-1}, maximum tomato fruit yield of 27.4 and 35.2 t ha^{-1} in 2 years was recorded. Total nitrogen uptake in drip irrigation was 8–11% higher than that of furrow irrigation. At the highest level of applied nitrogen (120 kgN ha^{-1}), total average N uptake of 2 years was 64.5 (1995) and 104.7 kg ha^{-1} (1996). The apparent N recovery was 82.5% at 48 kgN ha^{-1} in comparison with 47.9% at 120 kgN ha^{-1} during 1996. Stomatal resistance was higher in furrow irrigation than that of drip system at various plant height. Lower leaf had less resistance than upper leaf irrespective of irrigation methods.

Keywords: Fertigation; Water use efficiency; Drip and furrow irrigation; Canopy temperature; Stomatal resistance; Soil moisture stress

1. Introduction

Efficient use of water in any irrigation system is becoming important particularly in arid and semiarid region where water is a scarce commodity. In furrow and border irrigation systems, loss of applied irrigation water from reservoir to the field under unlined irrigation system is 71% (Navalawala, 1991). Such huge amount of water loss causes abundant nutrient loss through seepage/percolation. However, drip irrigation reduces deep percolation, evaporation and controls soil water status more precisely within the crop root zone. Similarly in fertigation, applied fertilizer through the drip system is placed to the active plant root zone and improves fertilizer use efficiency. Among major plant nutrients, nitrogen is

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usually limited in crop growth because of leaching loss, ammonia volatalization and denitrification. With the result of these major pathways of N loss, its utilization efficiency decreases considerably. Worldwide, nitrogen use efficiency (NUE) for cereal production is approximately 33% and the unaccounted 67% is due to various pathways of nitrogen loss which represents a $15.9 billion annual loss of nitrogen fertilizer (Raun and Johnson, 1999). Similar to frequent application of water, optimum split applications of fertilizer improves quality and quantity of crop yield than the conventional practice and Miller et al. (1976) observed higher tomato yield through fertigation than banded and furrow irrigation or banded and then trickle irrigated. Similarly, seven fertilizer application splits at weekly intervals produced higher yield as compared to the fertilizer applied just before planting (Locascio and Smajstrala, 1995). With regards to water use efficiency Chartzaulakis and Michelakis (1988) at Padua, Italy reported higher water use efficiency under controlled environmental condition in drip irrigation over furrow irrigation at -20 kPa soil water potential with no significant difference in crop yield. In this experiment, the amount of water applied to the tomato crop during September–June in drip irrigation was 37% less than the furrow irrigation. At the same research station, Michelakis and Chartzaulakis (1988) also reported a similar trend with higher water use efficiency, when irrigation through drip was given at -60 kPa soil water potential during fruiting stage and at -20 kPa soil water potential during rest of the growth period as against the lower water use efficiency in case where drip irrigation was given very frequently at -20 to -10 kPa soil water potential during fruiting and later. However, under Indian condition where major vegetable crops are grown in various natural environmental and soil conditions, the water use efficiency was lower in surface irrigation than drip irrigation (Pandey and Mahajan, 1999), however under controlled environmental condition, the water use efficiency was higher than in crops grown under natural environmental condition (INCID, 1994). Drip irrigation in USA increased yield of tomato and water use efficiency by 19 and 20%, respectively, over surface irrigation (Pruitt et al., 1989).

The use of canopy temperature to assess moisture stress in plant is measured with the help of infrared thermometer and is used as an irrigation scheduling criteria such as the Crop Water Stress Index or Stress Degree-day (Idso et al., 1981). Similarly the stomatal resistance/conductance depends on the water uptake rate of plants. However, the water extraction rate from soil profile is governed by the availability of moisture in the soil profile. Under inadequate water supply, the stomatal resistance increases and under adequate supply it decreases. Hence, this criteria is quite effective to monitor moisture stress in plants (Katerji et al., 1987).

Considering the importance of drip fertigation, water and fertilizer saving technique, importance of canopy temperature and stomatal resistance as plant indicators for scheduling irrigation, an experiment was conducted for 2 years with three and five levels of nitrogen during 1995 and 1996, respectively, in drip and furrow irrigation to assess fertilizer use efficiency, water use efficiency and the magnitude of moisture stress on the yield of tomato crop.

2. Materials and methods

The experiment was conducted on tomato (c.v. Dhanashree) during the wet seasons of 1995 and 1996 in clay loam and clay soils, respectively, at Research Farm of Mahatma Phule Agricultural University, Rahuri (Maharashtra). The site is situated on the cross point of 74°34′ longitude, 19°1′ latitude at an altitude of 447 m above mean sea level. The soil water content (w/w%) of clay loam at field capacity was 37.6, 36.0, 34.0 and 34.0% and at permanent wilting point 18.7, 17.2,17.0 and 16.4% in 0–15, 15–30, 30–45 and 45–60 cm soil depth, respectively. The corresponding bulk density was 1.26, 1.30, 1.32 and 1.36 Mg m^{-3}. For estimating important major plant nutrients, soil samples from 0 to 30 cm depth were collected from each plot and mixed thoroughly. Available nitrogen in soil was estimated by the alkaline permanganate method (Subbaiah and

Asija, 1956), available phosphorus by the sodium bicarbonate solution and available potassium by the ammonium acetate method (Jackson, 1973). Other physical and chemical properties of soils are given in Table 1. The treatments comprised two method of irrigation viz. furrow and drip with three levels of nitrogen (72, 96 and 120 kgN ha^{-1}) during 1995 and five levels (control, 48, 72, 96 and 120 kgN ha^{-1}) during 1996. These treatments were replicated four times in a randomized split plot design with a plot size of 6.0×4.8 m^2. In furrow, irrigation was applied at 60 mm cumulative pan evaporation (CPE) with 6 cm depth of water each time and in drip at 2 days interval based on 2 days CPE, different crop coefficient i.e. ratio of actual evapotranspiration of any crop to potential evapotranspiration of reference crop (kc values viz. 0–30 day after planting (DAP) = 0.6 kc; 30–45 DAP = 0.85 kc and 45 DAP above = 1.05 kc) and 60% wetted area of 60 cm emitters and 120 cm lateral spacing. If rainfall occurred within 2 days of an irrigation event, that amount was deducted before applying irrigation water. A water meter was also installed in the main pipeline to monitor the amount of water applied. The design specifications of drip units were a main line 50 mm, sub-main 32 mm, lateral 16 mm diameter, emitters (pressure compensating) discharge rate 4.0 l h^{-1}, operating pressure −100 kPa. The lateral was placed between two row in paired row planting, i.e. 45 cm and thus the distance from emitter source to plant row was only 22.5 cm.

Table 1
Physico-chemical properties of the experimental field (0–30 cm depth)

Properties	1995	1996
Textural class	Clay loam	Clay
Sand (mg g^{-1} of soil)	348	220
Silt (mg g^{-1} of soil)	292	274
Clay (mg g^{-1} of soil)	359	504
Available nitrogen (mg kg^{-1} of soil)	106	184
Available phosphorus (mg kg^{-1} of soil)	12	11
Available potassium (mg kg^{-1} of soil)	290	351
Organic carbon (g kg^{-1})	2.7	5.1
pH (1:2 soil water ratio)	8.2	8.5
EC (dS m^{-1})	0.25	0.17
Infiltration rate (mm h^{-1})	7.1	6.3

In the drip treatment, nitrogen levels were applied in ten equal splits at 8-day interval through irrigation water, which was passed through a fertilizer tank to which the calculated quantity of urea was added. In each plot a polypropeline ball valve of 32 mm size was provided to regulate the fertilizer levels. In furrow irrigation, nitrogen was applied in two equal splits i.e. at planting and one month thereafter. Recommended dose of phosphorus and potassium at 26.2 and 49.8 kg ha^{-1}, respectively, were applied at planting only. Planting of tomato seedlings was done with a crop geometry of $45–75 \times 60$ cm^2 (paired row) in the drip method and 60×60 cm^2 in the furrow method on August 16, 1995 and July 20, 1996. The crop was harvested (final picking) on January 4, 1996 and October 16, 1996. During crop growing periods, total rainfall was 502.6 mm in 1995 and 312.4 mm in 1996. To evaluate magnitude of moisture stress in plant and soil in both drip and furrow irrigation, canopy temperature was measured periodically with the tela temp infrared thermometer, the stomata resistance with AP4 steady state porometer. Air temperature was taken from meteorological observatory which was 20 m away from the experimental plots. Similarly the soil moisture distribution pattern in both irrigation treatments was monitored with a neutron moisture meter.

3. Results

3.1. Yield

Tomato fruit yield was 23–29 t ha^{-1} (1995) and 30–36 t ha^{-1} (1996). Fruit yield was significantly increased in drip irrigation by 12.5% as compared to furrow irrigation during 1995, however, it was not-significant during 1996. In both years shoot yield though was not influenced by irrigation treatments but during 1995, the increase in shoot yield in drip irrigation was 11.8% (Table 2). Significant reduction of tomato fruit yield in furrow irrigation could be due to the occurrence of moisture stress in each irrigation cycle as irrigation was applied at 16–18-days interval depending upon the designed CPE (60 mm) and

Table 2
Effect of irrigation methods and nitrogen levels on yield, N uptake and N recovery

Treatment	Fruit yield (t ha^{-1})		Shoot yield (t ha^{-1})		N uptake (kg ha^{-1})						Apparent N recovery (%)[c]
					Marketable+non-marketable		Shoot		Total		
	1995	1996	1995	1996	1995	1996	1995	1996	1995	1996	1996
Irrigation method											
Drip[a]	27.47	30.6	3.23	2.09	44.28	80.4	17.22	8.7	61.50	89.1	–
Furrow[a]	24.42	29.5	2.89	1.92	40.64	74.6	14.84	8.1	55.34	82.7	–
LSD (0.05)	1.48	NS	NS	NS	1.97	NS	1.81	NS	3.15	NS	–
Nitrogen (kg ha^{-1})											
0[b]	–	17.8	–	1.15	–	42.7	–	4.5	–	47.2	–
48[b]	–	30.8	–	2.00	–	78.9	–	7.9	–	86.8	82.5
72[b]	24.42	32.5	2.65	2.06	39.83	83.9	13.19	8.4	53.03	92.3	62.6
96[b]	25.99	34.1	2.97	2.38	42.48	88.0	15.49	10.1	57.76	98.2	53.1
120[b]	27.43	35.2	3.58	2.54	45.07	93.8	19.40	10.9	64.48	104.7	47.9
LSD(0.05)	1.48	1.65	0.45	0.82	2.43	4.9	2.22	2.43	3.87	4.8	–
Irrigation × nitrogen	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

[a] The values are average over nitrogen levels.

[b] The values are average over irrigation methods.

[c] Apparent N recovery from total N uptake (%) = {[(N uptake in fertilized plot)−(N uptake in control plot)/N fertilizer]} × 100 (Crasswell and Godwin, 1984).

the amount of rainfall received between two irrigation cycles.

Nitrogen response to fruit and shoot yield was significant and the response function between yield and nitrogen was quadratic in both years. During 1995, the magnitude of increase in fruit yield was 6.4 and 12.3% higher at 96 and 120 kgN ha^{-1}, respectively, as compared to 72 kgN ha^{-1}. During 1996, there was an increasing trend with increasing nitrogen level. The magnitude of increase in yield at 48, 72, 96 and 120 kgN ha^{-1} doses over unfertilized control were 73, 82.5, 91.6 and 97.7%, respectively. To ascertain the economic dose of nitrogen for tomato under the prevailing soil and environmental condition, fruit yield (Y) vs nitrogen levels (N) was fitted in second degree polynomial and the equations obtained are

$$Y = 18.83 + 0.08638N - 0.0001226N^2 \quad (r^2 = 0.17, n = 24) \text{ for } 1995 \tag{1}$$

$$\mathrm{Y} = 18.01 + 0.31465N - 0.00146N^2 \quad (r^2 = 0.92, n = 40) \text{ for } 1996 \tag{2}$$

where, Y = estimated yield (t ha^{-1}) and N = nitrogen level (kg ha^{-1}).

For estimation of economic optima, cost of nitrogen per kg = Rs. 8.00 and market rate of tomato per quintal = Rs. 900 were considered.

On the basis of the above Eq. (2), the economic optimum was worked out for the year 1996 only since the fruit yield for the year 1995 was not influenced by varying nitrogen levels as indicated by the low coefficient of determination ($r^2 = 0.17$). The economic dose of nitrogen for tomato was 104.7 kgN ha^{-1} with an optimum yield of 34.85 t ha^{-1} (Fig. 1a). For 1996, the maximum estimated nitrogen dose and fruit yield was 107.75 kg ha^{-1} and 34.96 t ha^{-1}, respectively. NUE during 1996 was in decreasing trend with increasing nitrogen levels: the magnitude being 270.8, 204, 169.8 and 145 kg fruits kg^{-1} applied nitrogen at 48, 72, 96 and 120 kg ha^{-1}, respectively. This type of trend is normal and reflects that more soil nitrogen is taken up with decreasing nitrogen rates to meet nitrogen requirement of crop. During initial growth stages, plants require a limited quantity of nutrients but the requirement increases in later stages. Hence, instead of applying only two split applications of nitrogen in furrow irrigation, ten splits through drip produced all the time higher fruit yields and the yield obtained at 72 kgN ha^{-1} was equal (25.49 t ha^{-1}) to the yield obtained at 120 kgN ha^{-1} dose (25.84 t ha^{-1}) in furrow irrigation (Table 3). During 1996, fruit yield at 72 kgN ha^{-1} in drip irrigation was same 33.6 t ha^{-1}; the same yield was obtained in furrow irrigation at 96 kgN ha^{-1} (Table 4). Thus proper utilization of applied nitrogen resulted in substantial saving of nitrogen in drip irrigation which was also attributed due to adequate amount of water in root zone.

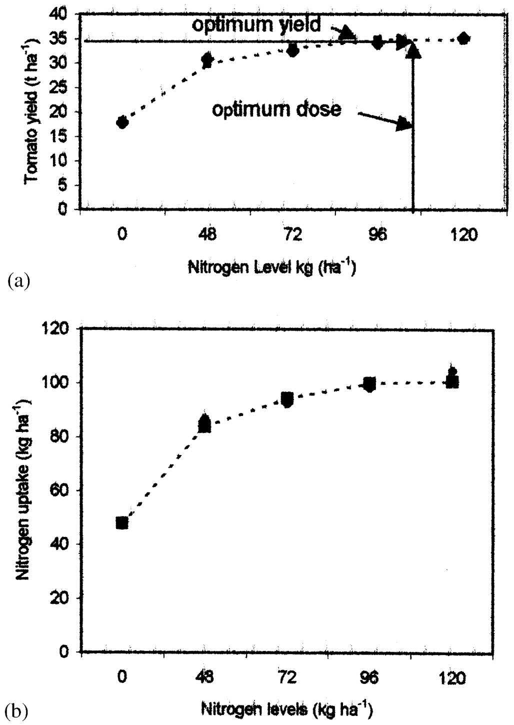

Fig. 1. (a) Nitrogen response and economic optima of tomato crop (1996). (b) Effect of nitrogen levels on nitrogen uptake (1996). (····■····) Estimated; (◆) observed.

3.2. Nitrogen uptake/recovery

On dry weight basis, N concentration and then N uptake were determined from marketable and non-marketable fruits and shoots. During 1995, nitrogen concentration in fruits varied from 20.8 to 20.3 mgN g^{-1} dry fruits in drip method and

Table 3
Effect of irrigation and nitrogen levels on tomato yield and N uptake (1995)

Irrigation method	N level (kg ha^{-1})				N level (kg ha^{-1})			
	72	96	120	Mean	72	96	120	Mean
	(a) *Tomato yield* (t ha^{-1})				(b) *Shoot yield* (t ha^{-1})			
Drip	25.49	27.99	29.02	27.47	2.73	3.12	3.86	3.23
Furrow	23.43	24.00	25.84	24.42	2.56	2.82	3.30	2.89
LSD (0.05)	$I = 1.48$	$N = 1.81$	$I \times N =$ NS		$I =$ NS	$N = 0.45$	$I \times N =$ NS	
	(c) *Dry fruit wt* (t ha^{-1})				(d) *N uptake in fruits* (kg ha^{-1}) (good and damaged)			
Drip	1.62	1.79	1.86	1.76	41.03	44.74	47.08	44.28
Furrow	1.54	1.57	1.70	1.60	38.64	40.22	43.07	40.64
LSD (0.05)	$I = 0.096$	$N = 0.118$	$I \times N =$ NS	$I = 1.97$	$N = 2.43$	$I \times N =$ NS		
	(e) *N uptake in shoot* (kg ha^{-1})				(f) *Total N uptake* (kg ha^{-1})			
Drip	13.89	16.23	21.53	17.21	54.92	60.98	68.61	61.50
Furrow	12.50	14.76	17.27	14.81	51.13	54.55	60.34	55.34
LSD (0.05)	$I = 1.81$	$N = 2.22$	$I \times \mathrm{N} =$ NS		$I = 3.15$	$N = 3.87$	$I \times N =$ NS	

Table 4
Effect of methods of irrigation and nitrogen levels on fruit yield and N uptake (1996)

Irrigation method	N level (kg ha^{-1})						N level (kg ha^{-1})					
	0	48	72	96	120	Mean	0	48	72	96	120	Mean
	(a) *Fruit yield, marketable* (t ha^{-1})						(b) *Fruit yield, non- marketable* (t ha^{-1})					
Drip	17.8	31.5	33.6	34.7	35.7	30.6	4.5	6.8	6.8	6.7	6.8	6.3
Furrow	17.7	30.2	31.5	33.6	34.7	29.5	3.8	7.0	7.2	6.6	6.3	6.2
LSD (0.05)	I = NS	N = 1.65	$I \times N$ = NS				I = NS	N = 0.74	$I \times N$ = NS			
	(c) *Shoot weight* (t ha^{-1})						(d) N *uptake in fruit (good+damaged)* (kg ha^{-1})					
Drip	1.31	2.08	2.11	2.36	2.58	2.09	44.6	81.3	87.1	92.3	96.7	80.4
Furrow	1.00	1.93	2.01	2.40	2.50	1.92	40.7	76.6	80.8	83.8	91.0	74.6
LSD (0.05)	I = NS	N = 0.032	$I \times N$ = NS				I = NS	N = 4.9	$I \times N$ = NS			
	(e) *N uptake in shoot* (kg ha^{-1})						(f) *Total* N *uptake* (kg ha^{-1})					
Drip	3.1	8.2	8.7	10.3	11.1	8.7	49.7	89.5	95.8	102.6	107.8	89.1
Furrow	3.9	7.7	8.2	10.0	10.7	8.1	44.6	84.3	89.0	93.8	101.7	82.7
LSD (0.05)	I = NS	N = 2.43	$I \times N$ = NS				I = NS	N = 4.8	$I \times N$ = NS			

19.8–20.5 mgN g^{-1} dry fruits in furrow irrigation. In dry shoot, the corresponding values were 5.1–5.6 and 4.9–5.3 mgN g^{-1} dry matter, N concentration in dry tomato fruits ranged 13.6–15.2 mgN g^{-1} dry fruits in drip and 13.3–14.9 mgN g^{-1} dry fruits in furrow irrigation. With different N levels, there was a slight non-significant increase in N concentration.

Nitrogen uptake was significantly influenced by the irrigation schedule during first year. Due to frequent application of irrigation and fertilizer in drip irrigation, nitrogen was effectively utilized, as there was direct contact with the root system with negligible N loss through leaching, as applied irrigation water did not move beyond 30 cm soil depth. But in furrow irrigation, since nitrogen was applied only in two equal splits, effective utilization was reduced particularly during the drying cycle as soil moisture was depleted with time. Hence, total N uptake of plants in furrow irrigation was reduced by 10% during 1995 as compared to the drip method. Similarly in marketable plus non-marketable fruits and shoot, N uptake was declined significantly by 8.2 and 13.8%, respectively (Table 3). During 1996, total N uptake declined by 7.2% in furrow irrigation. A similar trend was observed in fruits and shoots N uptake (Table 4). With respect to N levels on N uptake, there was a progressive increase in N uptake with increasing nitrogen levels in both the years, the magnitude being 21.6 and 121.8% at the highest level of nitrogen (120 kg ha^{-1}) over the lowest level of nitrogen in 1995 and 1996, respectively. The apparent N recovery percentage was higher at the lowest N level and decreased with increasing N levels. It is thus inferred that plant extracted more mineralized nitrogen to meet its demand under constraint of nitrogen.

To ascertain optimum N uptake in tomato fruits, total N uptake vs N applied was fitted in second degree polynomial and the equations obtained are

$$Y = 50.6788 - 0.091N + 0.0017N^2 \quad (r^2 = 0.45, n = 24)\ (1995) \tag{3}$$

$$Y = 47.9009 + 0.9517N - 0.004258N^2 \quad (r^2 = 0.89, n = 40)\ (1996) \tag{4}$$

Y = estimated N uptake (kg ha^{-1}) and N = nitrogen level (kg ha^{-1})

On the basis of above equations, optimum and maximum total estimated N uptake at 120 kgN ha^{-1} level during 1996 was 110.70 and 111.75 kg ha^{-1}, respectively, however, during 1995 since the coefficient '*c*' is positive, N uptake is in increasing trend (Fig. 1b).

3.3. Irrigation requirement and water use efficiency

In 1995 and 1996, the amount of irrigation water applied in the furrow system was higher by 12.2 and 5.6 cm, respectively, than the drip method (Table 5). In the first year the irrigation treatment was imposed in November, December and up to January 4, 1996, and four irrigations with 24 cm of irrigation water were applied. In case of drip irrigation, depending upon 2 days CPE, the amount of irrigation water applied the same period was 14 cm. In the early growth period i.e. in August September and October a rainfall of about 506 mm, during 30 rainy days was quite effective to meet evaporative demand. During 1996, the total rainfall of 312 mm, occurred in 39 rainy days in July, August, September and up to October 19, 1996. As a result of adequate distribution of rainfall during crop growth period, tomato crop in the second year required less irrigation water as compared to the first year.

The amount of irrigation water applied plus the effective rainfall were considered as total water used by the plant. On the basis of total water use and tomato yield at different nitrogen levels under both drip and furrow irrigation, the water use efficiency was computed. As shown in Table 6 WUE in drip irrigation, on an average over nitrogen levels was 68 and 76.8% higher over furrow irrigation in 1995 and 1996, respectively. Similarly the nitrogen application improved the WUE.

3.4. Water movement

Neutron moisture meter to assess moisture stress and profile moisture flux during the year 1995 was monitored by the soil water content in the soil profile. In furrow irrigation, moisture

Table 5
Irrigation requirement of crop and water use efficiency

Details	Drip irrigation[a]		Furrow irrigation[a]	
	1995	1996	1995	1996
Irrigation water applied (cm)	20.9	12.4	33.1	18
Total rainfall (cm)	50.26	31.24	50.26	31.24
Effective rainfall (cm)	17.04	8.84	23.57	18.3
Total water use (cm)	37.94	21.24	56.67	36.3
Water use efficiency (marketable fruit yield in kg ha cm^{-1} of total water used)	725	1442	431	813

[a] The values are average over nitrogen levels.

content (v/v%) before each irrigation in 15 and 30 cm soil depth was quite high than 45 and 60 cm soil depth (Fig. 2). In drip irrigation, water content at source point remained high over furrow irrigation in all soil depth (Fig. 3a). The moisture content at 30 cm radial distance from emitter and perpendicular to the lateral was slightly higher than the source of emitter at 15 cm soil depth as water front moved up to 45 cm away in redistribution process (Fig. 3b). Similarly, the moisture content at 30 cm away and parallel to the lateral in all soil depth was almost same like the source of emitter (Fig. 3c). From the observed soil moisture content (v/v%), available soil moisture was estimated by considering per layer the bulk density, the water content at the field capacity and permanent wilting point. It was observed that in furrow irrigation, depletion of available water just before irrigation, on an average of four soil depth was 48–60.2%. In case of drip irrigation, depletion of available moisture at source of emitter, on an average was 29.1–36.7% in 0–60 cm depth. At 30 cm radial distance and at 30 cm away from source of emitter but parallel to lateral, on an average of four layers, the depletion of available moisture ranged 31.2–39.5% and 27.7–30.6%, respectively. During 1996, since the experimental field was clay in texture and due to well distributed rainfall, crops did not suffer from moisture stress in which only 34.5% depletion of available water in 0–60 cm soil depth occurred in furrow irrigation as against 7.5% in drip irrigation.

3.5. *Canopy temperature*

During 1995, canopy temperature was measured with the help of IR thermometer at solar noon (1200–1400 h) in all treatment levels. Since there was sufficient rain up to October 19, 1995, measurement of plant canopy temperature could be initiated from October 24, 1995 and continued up to December 16, 1995. It was found that the

Table 6
Water use efficiency (marketable fruit yield in kg/ha cm of total water used) in drip and furrow irrigation at different nitrogen levels

Irrigation method	Nitrogen level (kg ha^{-1})					
	0	48	72	96	120	Mean
1995[a]						
Drip	–	–	669	738	765	724
Furrow	–	–	414	424	456	431
1996[b]						
Drip	838	1471	1580	1625	1681	1439
Furrow	487	832	868	926	956	814

[a] LSD (0.05) irrigation method, 44.5; nitrogen, 81.8; interaction, NS.

[b] LSD (0.05) irrigation method, 157.3; nitrogen, 59.6; interaction, 114.5.

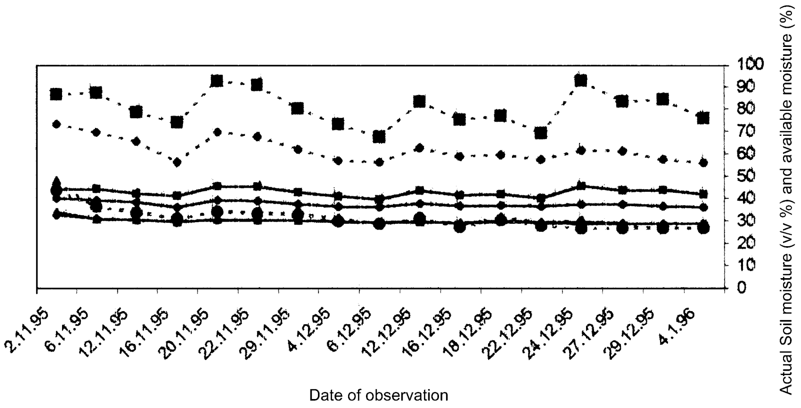

Fig. 2. Actual and available soil moisture in furrow irrigation in tomato during 1995–1996. (—■—) Moisture at 15 cm; (—◆—) moisture at 30 cm; (—●—) moisture at 45 cm; (—▲—) moisture at 60 cm; (····■····) available moisture at 15 cm; (····◆····) available moisture at 30 cm; (····●····) available moisture at 45 cm; (····▲····) available moisture at 60 cm.

plant canopy temperature in drip irrigation was lower than in furrow irrigation since irrigation water applied with the drip method on every second day was equal to crop ET for that period and there was constant supply of water through transpiration pool, however, in furrow irrigation, adequate cooling occurred immediately after irrigation, thereafter the resistance of water flow through the soil–plant–continuum particularly at the point of stomata cavities reduced transpiration cooling and the plant leaves emitted higher temperature. In case of existing experiment, canopy temperature–ambient temperature ($T_c - T_a$) in drip irrigation was between +2.0 and +3.3 °C which was highest because in the paired row planting method, 75 cm empty space as well as irrigation at 60% wetted area might have influenced the increase in canopy temperature. In furrow irrigation, $T_c - T_a$ reached maximum up to +4.1 °C towards drying i.e. before irrigation and minimum of −1.2 °C on 3-day after irrigation where the complete plot area (ridge and furrow) was wet and had an identical microclimate (Fig. 4).

Before irrigation, leaf temperature, which was measured by a steady state porometer was higher in furrow than drip irrigation. In furrow irrigation, the leaf temperature on 1 November was 30.1, 30.4 and 30.8 °C in lower, middle and upper leaves, respectively, but on third day (irrigation was applied on 31 October) the leaf temperature dropped down at substantial rate to 28.3, 27.8 and 27.5 °C in order. This trend indicates increasing cooling. Similarly in drip irrigation also, maximum temperature was observed in upper leaves followed by middle and lower leaves but less warmer than furrow irrigation except on 20 November and 24 December as observations were taken after 2–3 day of irrigation in furrow irrigation.

3.6. Stomatal resistance

The observations on above parameters were recorded from three plants of each nitrogen level. With drip stomatal resistance in general was less than furrow irrigation except during 2–3 day after irrigation, the stomatal resistance in furrow irrigation was reduced significantly because of sufficient water in mesophyll cell, stomata cavities and this was again increased towards depletion of soil moisture just before irrigation. The stomatal resistance in the drip irrigation was not reduced substantially and remained stable even just before irrigation. The stomatal resistance towards maturity under both irrigation methods increased due to senescence of leaves. In case of furrow irrigation, stomatal resistance at the time of irrigation ranged 197–257 s m^{-1} in upper leaves, 143–256 s m^{-1} in middle and 100–217 s m^{-1} in lower leaves. But in case of drip irrigation, the corresponding values were 131–236, 126–232 and 113–210 s m^{-1}. This

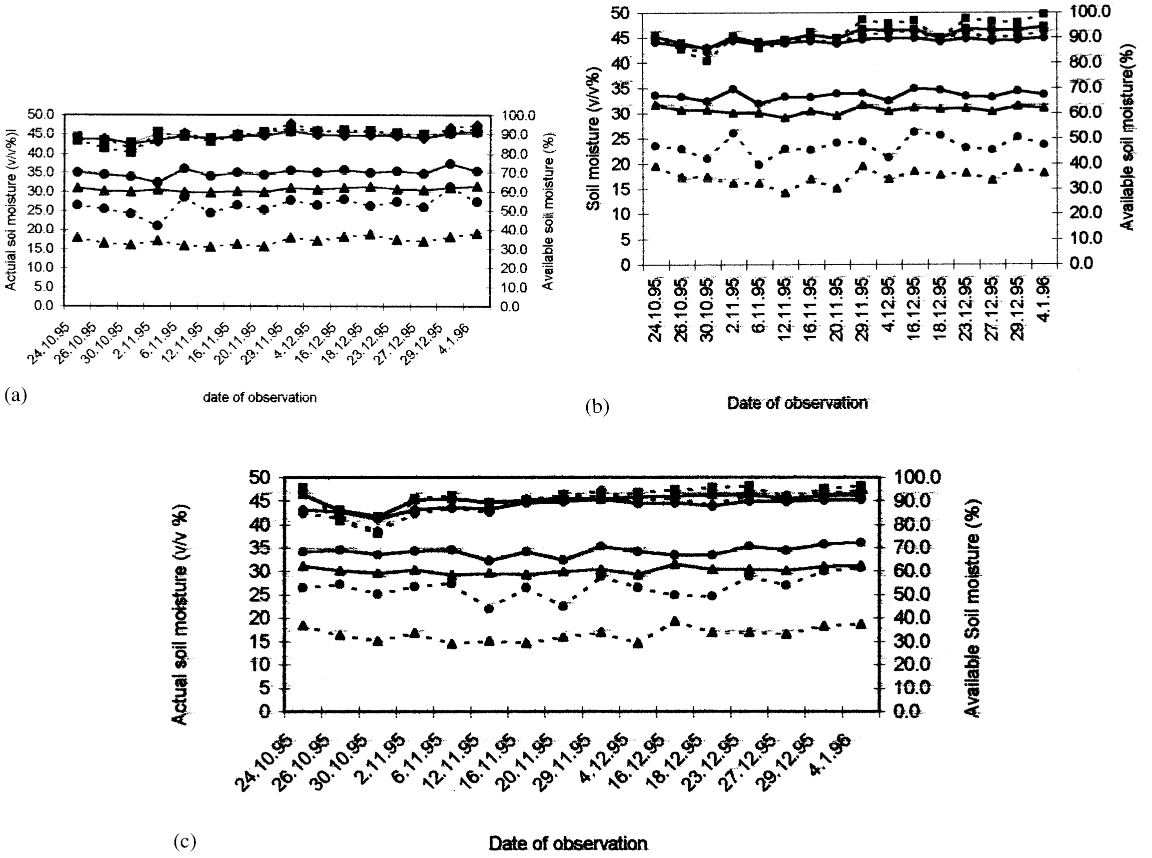

Fig. 3. (a) Actual and available soil moisture at the source of the emitter in tomato during 1995–1996. (b) Actual and available soil moisture at 30 cm radial distance from the emitter during 1995–1996. (c) Actual and available soil moisture at 30 cm distance parallel to the lateral during 1995–1996. (—■—) Moisture at 15 cm; (—◆—) moisture at 30 cm; (—●—) moisture at 45 cm; (—▲—) moisture at 60 cm; (····■····) available moisture at 15 cm; (····◆····) available moisture at 30 cm; (····●····) available moisture at 45 cm; (····▲····) available moisture at 60 cm.

type of trend explains the immediate water flow in bottom leaves followed by middle and upper leaves.

4. Discussion

During winter 1995, significant reduction in fruit yield of tomato was observed in furrow irrigation due to higher depletion of available soil moisture from 0 to 60 cm soil depth (Fig. 2) as irrigation was applied at 16–18-days interval. Occurrence of such high magnitude of moisture stress in each irrigation cycle also reduced shoot yield by 10.5% but the effect was statistically not-significant. This is in confirmation with the observations made by Kramer (1959) that inadequate amount of available water in soil and subsequently in plant during crop growth period hampers various physiological processes in plant and finally the crop yield. In case of drip irrigation, however, the depletion of available soil moisture from same soil depth was quite low (Fig. 3a, b and c) as very frequent applications of irrigation water (2-day interval) created an adequate environment in soil–plant–atmosphere system and helped for proper growth of the tomato crop. As a result, in the present experi-

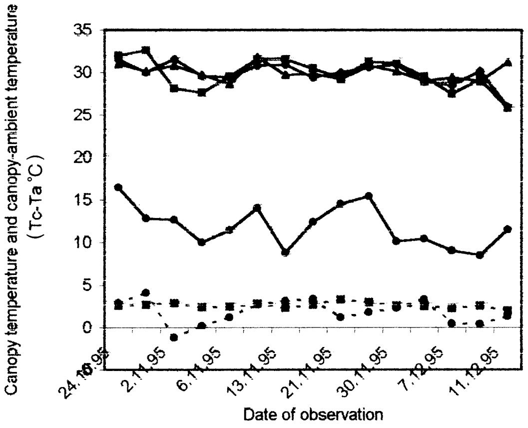

Fig. 4. Canopy temperature (T_c), canopy temperature–ambient temperature ($T_c - T_a$), and maximum and minimum air temperature. (—■—) Canopy temp. drip; (—◆—) canopy temp. furrow (—▲—) air temp. max.; (—●—) air temp. min.; (····■····) $T_c - T_a$, drip; (····●····) $T_c - T_a$, furrow.

ment, drip irrigation recorded 68–76.8% higher water use efficiency than that of furrow irrigation. The water use efficiency during winter 1996, in both irrigation methods was, however, higher than winter 1995 as the rainfall received during 1996 was well distributed and plants did not suffer from moisture stress for a longer period. At Rahuri (Maharashtra), Bangal et al. (1987) reported 4.8% higher tomato yield with 45% saving of water in drip irrigation than furrow irrigation. Other investigators have also reported higher yields and water use efficiency for tomato and other crops under drip irrigation (Bucks et al. 1974; Grimes et al. 1976; Chartzaulakis and Michelakis, 1988 and Michelakis and Chartzaulakis, 1988). In drip irrigation, ten splits of nitrogen at weekly interval recorded higher fruit yield than two equal splits in surface method. Generally young plants need lower amounts of nutrients because their absolute growth rates (mg dry matter produced per unit time) are low. In this experiment, split application of nitrogen in drip irrigation coincided with the actual needs of the crop up to 80 days period; favoured good growth and produced maximum fruit yield. Similarly, the placement of nitrogen just near the base of plant became quite useful as there was no leaching loss and the optimum soil moisture which was prevailing within crop root zone resulted in a better utilization of applied nitrogen. Response to various levels of nitrogen on tomato fruit yield was quadratic in both the years, however, during 1996, the increasing fruit yield with each increment of nitrogen level was in higher magnitude up to 96 kgN ha^{-1} dose, and beyond this level, the rate of increasing fruit yield was marginal. Hence, the economic optimum under such soil and environmental situation was 104.7 kgN ha^{-1}. Under limited supply of available nitrogen in growing media, plants absorb more mineralized soil nitrogen to meet their demand. In the present experiment, the NUE was maximum in control plot and decreased with increasing each unit of nitrogen (Yoshida, 1978; Chauhan and Mishra, 1989).

Periodic soil moisture movement presented in Fig. 3a–c showed that the soil moisture front remained stable even after irrigation at 45 and 60 cm soil depth. This may be due to low water retention capacity of lower layer. But in upper layer i.e. 15 and 30 cm depth, there was an increase in water content just after surface irrigation and depletion occurred when redistribution started. In case of the drip irrigation, at the source of emitter, the soil moisture in 45 and 60 cm soil depth was higher as compared to surface irrigation because of frequent irrigation. Higher soil moisture in drip irrigation towards both vertical and horizontal direction showed a well designed lateral and emitter spacing, which can provide adequate amount of water in adopted paired row planting.

In the present study, the magnitude of canopy temperature in surface and drip irrigation was clearly distinguished at the time of irrigation in surface irrigation. In case of drip irrigation, the difference between canopy temperature and ambient temperature ($T_c - T_a$) at the time of irrigation was +2.4 to +4.3 °C whereas in surface irrigation where the depletion of available soil moisture was higher, the $T_c - T_a$ was maximum of +4.7 °C. The occurrence of such a trend in plant canopy could be due to more water loss from leaves than uptake. Heermann and Duke (1978) showed that for irrigated maize, a temperature difference ($T_c - T_a$) greater than +1.5 °C resulted in yield decrease. Clawson and Blad (1982) started irrigation when the canopy temperature was either 1.0 or 3.0 °C warmer than the irrigated plot.

In the present experiment, the stomatal resistance was higher in surface irrigation as irrigation scheduling was done at 60 mm CPE value (16–18-days interval) than in drip irrigation which was applied at 2-day intervals. With the result of adequate soil moisture with drip irrigation, the flow of water from soil to the atmosphere through the plant system was comparatively higher than with surface irrigation. Vijaykumar et al. (1998) irrigated rubber trees (*Hevea brasiliensis*) and recorded higher stomatal resistance in check basin and lower stomatal resistance in drip irrigation.

5. Conclusion

In commercial cash crops, adoption of drip irrigation saves a substantial amount of water as this commodity is very important for over all development of any sector. Use of this system in such high value cash crops economized irrigation water up to 37% and increased fruit yield up to 12.5%. Similarly water use efficiency of drip irrigation was higher by about 72% as compared with furrow irrigation. In paired row planting, nitrogen application through drip was effective as water front reached the base of the plant quickly and thus the applied nitrogen was utilized efficiently. Similarly, available water in the soil profile particularly in 15 and 30 cm soil depth was higher (82.9–93% and 82.4–95.5%) than in furrow irrigation (67.4–74.1% in 15 cm and 56.2–57.4% in 30 cm soil depth). Adoption of paired row planting not only saved fifty per cent lateral and emitter cost but also kept soil moisture in adequate quantity in both horizontal and vertical direction relative to the normal planting (60×60 cm^2). In case of drip irrigation, frequent application of nitrogen as urea followed by the formation of NH_4^+, its adsorption on soil clay minerals for a longer period followed by a gradual formation of nitrate nitrogen increased fertilizer use efficiency. In case of surface irrigation, more depletion of available soil moisture till the next irrigation reduced the N availability to plants. Hence, considering the above advantage, future studies on fertigation with combination of other major and even micro nutrients may help to improve quality and quantity of tomato fruits. Assessment of moisture stress in plant through changes in canopy temperature helps to monitor the magnitude of moisture stress and stress-degree day concept may be useful to follow irrigation schedule.

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