Soil Moisture Distribution under Different Emitters and Fertigation Levels and Its Effect on Tomato Yield

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A B S T R A C T

Field experiments were conducted in sandy clay loam soils to assess the effect of different levels of fertigation and emitter types on hydraulics of drip irrigation, movement of soil moisture distribution and yield of tomato. The three levels of fertigation *i.e.* fertigation with 100% recommended dose of fertiliser (RDF), 80% RDF and 60% RDF and four types of emitters viz. online pressure compensating (online pc), online non pressure compensating (online npc), inline pressure compensating (inline pc) and inline non pressure compensating (inline npc) emitters were tried in split plot design with three replications. The fertigation levels were allocated to main plots and the emitter types were assigned to sub plots. Water soluble fertilisers viz. urea, urea phosphate with SOP and sulphate of potash were used for fertigation. The emission uniformity test showed better results for pc emitters over npc emitters. The soil moisture distribution under various emitters indicated the highest moisture content below the emitters and it decreases as distance from emitter increases both horizontally and vertically. The treatment with 100% fertigation through online pc emitter based drip system results the maximum fruit tomato yield of 59.8 t/ha since this treatment maintained higher soil moisture contents both in horizontal and vertical direction below the emitter than all other treatments. Further the said treatment had the highest value of emission uniformity (99.04%) amongst all the treatments that have caused uniform distribution of water in the root zone resulting higher yield.

Introduction

The availability of water for irrigation is diminishing day by day throughout the world due to increasing demand from other sectors viz. industrial, urban and domestic uses. This has resulted in an increased threat to food security. Hence, irrigation methods are vital for efficient utilisation of this increased scar

resources. Deficit irrigation may become unavoidable in future due to scarcity of irrigation water. Though India has been expanding the irrigated area since independence but the irrigation efficiency has not achieved more than 40%. The surface irrigation practices such as check basin, furrow are inefficient, causing various problems including salinity, runoff and

contamination of water bodies. Therefore there is urgent need of maximising production per unit of water by adopting advanced method of irrigation like micro irrigation. Amongst different types of micro irrigation, drip irrigation has proved its superiority over other methods of irrigation due to direct application of water and fertiliser in root zone area of crop. In India the potential of drip irrigation is about 27 million ha as per report of task force on micro irrigation. Water saving and fertiliser saving in drip irrigation is to the tune of 39-100% and 40-60%, respectively.

Drip irrigation is an advanced method of irrigation in which water is applied in the crop root zone in order to meet the crop water requirement and maintain optimum soil moisture around the plants (Devi Aruna and Selvaraj, 2013). Water is applied directly at the crop root zone without wetting the entire surface area. This causes considerable saving of irrigation water (Bafna *et al.,* 1993). In addition to saving irrigation water, drip irrigation has other added advantages like better crop survival, higher yield and improved crop quality (Martin *et al.,* 1994; Prasad *et al.,* 2003; Kumar *et al., 2005*; Sharma and Kumar, 2007). Drip irrigation has been practised in a number of vegetables. Field experiment was conducted with drip irrigation in okra crop by Tiwari *et al.,* (1998) who reported higher fresh yield and benefit cost ratio (1.77) under drip irrigation as compared to furrow irrigation. Tiwari *et al.,* (2003) also conducted field experiments with drip and furrow irrigation in cabbage crop and reported 54% higher yield and 40% saving of costly irrigation water through drip irrigation compared to furrow irrigation. Antony *and* Singhdhupe (2004) tested the impact of drip irrigation on growth and yield of capsicum and found the maximum yield and growth of the crop in drip irrigation at 100% evapotranspiration rate in loamy soil of humid sub tropical region. Field experiment with drip

and furrow irrigation in brinjal and capsicum were conducted by Mohanty *et al.,* (2016) and Paul *et al.,* (2013), respectively in Odisha, India. It was reported that drip system gave the maximum fruit yield, yield attributing parameters and water use efficiency as compared to furrow irrigation. They reported considerable saving of irrigation water with yield improvement in drip irrigation as compared to conventional furrow irrigation.

In drip irrigation, the type of emitter plays a crucial role in uniform application and distribution of water in the crop root zone. Field experiment conducted by Capra and Scicolone (2004) with different types of emitters and filters for use of waste water by drip irrigation revealed that inline emitters and gravel filter were good combination over vortex emitter and screen filter. Tayel *et al.,* (2013) tried eight different types of emitters with reclaimed water and recommended pressure compensating emitters of short flow path for getting higher hydraulic performance of drip irrigation. Pei *et al.,* (2014) conducted study with online pressure compensating and online non-pressure compensating emitters and recommended online pressure compensating emitters for practical utilisation.

Drip irrigation system can easily be used for fertigation through which crop nutrient can be applied in real time. In drip fertigation, the water soluble fertilisers are applied to the root zone of plants which enhances application efficiency due to small quantity of fertilisers applied in frequent intervals. Fertigation reduces the fertiliser requirement and at the same time increases the yield in most of the vegetables. Drip fertigation on Assam lemon in alluvial sandy loam soils of Jorhat gave the maximum benefit cost ratio of 4.17 (Barua and Hazarika, 2014). Works on fertiliser use efficiency (FUE) in drip-fertigation system have been done by several researchers. Increase of FUE was observed with decrease

of fertigation level in the research works conducted by Rajan *et al.,* (2014) and Gupta *et al.,* (2014). Rajan *et al.,* (2014) recorded highest FUE when fertigation was done at 50% of recommended dose in tomato whereas Gupta *et al.,* (2014) recorded maximum FUE in tomato when fertigation was maintained at 60% of recommended dose. Water and nutrient movement in soil under drip irrigation is influenced by the type of soil and nutrient application (Thabet and Zayani, 2008). The moisture distribution patterns in the soil profile in drip fertigation are also governed by design parameters viz. location of drippers, application rates, frequency and amount of irrigation water which need to be investigated properly. The field study by Moncef *et al.,* (2011) in tomato and watermelon plots irrigated through drip irrigation with different emitter discharge rates inferred that wetting front depth was highly correlated with lateral spread of wetting front. Wetting front or wetted bulb coordinates in soil under surface drip irrigation were measured by Molavi *et al.,* (2012) for loamy and sandy loam soils with 2 different emitter discharges of 2 and 4 lph by using the trenching method. Kumar *et al.,* (2015) investigated the effect of dripper discharge at different system operating pressures on spatio-temporal soil moisture movement. The value of moisture contents varied significantly under different operating pressure and at different locations below and away from the dripper. The present study was undertaken (i) to assess the hydraulics of different types of emitters/drippers, (ii) to study the moisture distribution pattern below the emitters and (iii) to find out the impact of soil moisture distribution on yield of tomato.

Materials and Methods

Details of experimental site

The field experiments were conducted at farmer's field for two consecutive winter seasons of 2014 and 2015. The study site (20^0 15'N latitude and 86^0 10'E longitude) is located in Jagatsinghpur region of the state of Odisha, India. The region is characterised by hot and humid climate. The normal annual rainfall of study site is 1514 mm distributed over 66 rainy days. The rainfall occurs mainly due to South –West monsoon from mid June to mid October. The average maximum and minimum temperatures of the area are 32.5 and 23.4^0C, respectively and average relative humidity varies from 67 to 84%.

The experimental site had well drained sandy clay loam (75.8 % sand, 2% silt and 22.2% clay) soil having pH of 6.08. The bulk density of soil was 1.32 gm/cc and electrical conductivity was 0.05 dS/m.

The soil of the site had available N of 288.5 kg/ha (medium), P of 13.05 kg/ha (medium) and K of 132.9 kg/ha (medium). The field capacity and permanent wilting point of soil was found to be 24.6% and 7.4%, respectively on weight basis.

Experimental design

The field experiment was laid out in split plot design with twelve treatment combinations replicated thrice. The three fertigation levels viz.F1 =100% recommended dose of fertilisers (RDF), F2 = 80% RDF and F3 = 60% RDF were allocated to main plots and four types of emitters viz. E1 = online npc, E2 = online pc, E3 = inline npc and E4 = inline pc were allocated to sub plots.

Based on soil test report and regional recommendations, the recommended dose of fertiliser (RDF) was fixed at 125, 75 and 100 kg/ha N, P_2O_5 and K_2O, respectively. The drippers/emitters were spaced equally i.e. 40 cm apart in all four types of emitters. The discharge capacity of each emitter was 2 lph. The various treatments are defined in Table 1.

Drip fertigation system

The drip irrigation system was installed in a plot of 65 m x 32 m. The drip irrigation system had one hydrocyclone filter, one disk filter and ventury injector. The main plot was divided into 3 sub-plots catering to need of three replications. Each subplot was again divided to 12 plots of size 10 m x 5 m each. PVC pipes of 50 mm and 40 mm were used as main pipe and sub-main pipe and 12 mm lateral pipes were used for distribution network

Tomato seedlings of 30 days old were planted on 4 January 2014 and 3 January 2015. Gross and net plot sizes were 10.0 m x 4.8 m and 8.4 x 2.4 m, respectively. The crop in all treatments had row to row spacing of 1.2 m and plant to plant spacing of 0.4 m. The single lateral lines of 12 mm diameter low density polyethylene (LDPE) pipes were laid along the crop rows. The spacing between two adjacent laterals within plot was 1.2 m and spacing between emitters in each lateral were 0.4 m. The fertigation was applied in four growth stages of the crop i.e. crop establishment (20 days), crop development stage (30 days), mid season (30 days) and late season (30 days). Fertigation was done using water soluble grades of urea (46:0:0), urea phosphate with SOP (18:18:18) and sulphate of potash (0:0:50) through ventury injector at weekly intervals as shown in Table 2.

The amount of water (lit/day) applied through drip irrigation system to each plant was calculated using following equation (Pawar *et al.,* 2013)

$$V = ET_o \times K_c \times L_s \times E_s \times W_s / \eta \qquad (1)$$

where, V = volume of water applied (lit/day/plant), ET_o,= reference crop evapotranspiration (mm/day) calculated by Penman-Monteith method (Allen *et al.,* 1988),

K_c = crop coefficient; L_s and E_s = lateral and emitter spacing taken as 1.2 and 0.4 m, respectively, Ws = percentage wetted area factor and η = water application efficiency of the system assumed as 90% for all treatments and so in Eq. (1), while calculating the value of *V*, we use η as 0.90 for all treatments. The values of K_c of tomato for various growth stages were taken as 0.45, 0.75, 1.15 and 0.8 and values of Ws were assumed as 0.3, 0.45, 0.6 and 0.8 for crop establishment, crop development, mid season and late season stages, respectively (Panigrahi *et al.,* 2011). Volume of water so calculated was divided by the emitter/dripper discharge and the time of operation of drip system was then calculated. In drip system water was applied on alternate day. Hence while calculating values of V of a particular day, sum of two previous days ETo values was taken as ETo value in Eq. (1) and the amount of water so given as irrigation by drip system was used for plant consumption for 2 days.

Weather parameter during crop growing period

Daily values of maximum and minimum temperature (°C), maximum and minimum relative humidity (%), pan evaporation (mm) and wind speed (km/h) during the crop growth period in 2014 and 2015 are shown in Figure 1(a) and (b), respectively. There was no rainfall during the crop growing period in 2014 and 2015.

Emission uniformity (Eu)

The emission uniformity was studied to find out the emitter flow variation along the drip pipe line (Keller and Karmeli, 1974) which is defined as:

$$Eu = 100 \left[1 - \frac{1.27}{n^{0.5}} \times C_v \right] \times \frac{q_{min}}{q_{avg}} \qquad (2)$$

where, Eu = emission uniformity, C_v = manufacturer's coefficient of variation, n = number of emitters per plant (taken as 1 in this study), q_{min} = minimum emitter discharge rate for the minimum pressure in the section and q_{avg} = average emitter discharge rate.

Discharge from each emitter was collected in plastic beaker (catch can) for 30 minutes interval. The volume of water so collected was measured with help of measuring cylinder. These measured quantities were used for calculation of discharge which are used in Eq. (2) for computation of Eu. The values of Eu so calculated along with the statistical test (ANOVA) are shown in Table 3.

Hydraulics of drip emitters and soil moisture movement

Field experiment were done to study hydraulics of emitters and soil moisture movement under drippers for various treatments and finally to study their effect on tomato yield.

The soil moisture movement was observed at operating pressure of 0.8 kg cm^{-2}.The wetting front was recognised by the colour difference of wetted zone and surrounding soils. The horizontal and vertical wetting distances on the wetted face were recorded by measuring scale. However, the soil moisture contents were measured by a digital soil moisture meter at 0, 10, 20, 30, 40 cm distance away from the dripper and at different depths (10 cm interval upto 40 cm) below the dripper after 1 hour of operation. The readings were taken after 24 hours of drip operation.

Yield of tomato

Yield of tomato were recorded for each treatment. The ripe tomatoes were harvested on alternate day during 2nd to 4th week of April of each year. The pooled data of yield along

with the statistical analysis for all treatments is shown in Table 4.

Results and Discussion

Different fertigation levels failed to cause significant variation in emission uniformity. However, dripper/emitter types differed significantly for Eu values. The online pc emitter recorded the maximum emission uniformity of 98.42 % followed by inline pc emitters with Eu value of 95.73 %. Online pc emitters recorded 2.8% more Eu value over inline pc emitters. Similarly online npc emitters recorded 4.9% more emission uniformity value than inline npc emitters. Pressure compensating emitters performed better than npc emitters (Table 3).

Spatial soil moisture distribution

Spatial distribution of soil moisture was significantly different at different locations in horizontal and vertical direction from the dripper. The highest value of soil moisture content (24.5%) was observed below the dripper which decreased as the distance increased from the dripper. The soil moisture distribution under different emitters for various treatments were plotted taking into consideration the moisture content at 10 cm interval in both horizontal and vertical direction and using the SURFER software. It is observed that there is more uniform distribution of moisture under pc emitters as compared to npc emitters. The soil moisture distribution for different treatments under different types of emitters is shown in Figure 2.

Effect of fertigation and emitters on soil moisture distribution and impact on yield

Both fertigation level and emitter types exerted significant influence on fruit yield of tomato.

Table.1 Notations of various treatments adopted in the study

Sl. No.	Symbol for treatment combination	Treatment details
1	F_1E_1	100% RDF with online npc emitters
2	F_2E_1	80% RDF with online npc emitters
3	F_3E_1	60% RDF with online npc emitters
4	F_1E_2	100% RDF with online pc emitters
5	F_2E_2	80% RDF with online pc emitters
6	F_3E_2	60% RDF with online pc emitters
7	F_1E_3	100% RDF with inline npc emitters
8	F_2E_3	80% RDF with inline npc emitters
9	F_3E_3	60% RDF with inline npc emitters
10	F_1E_4	100% RDF with inline pc emitters
11	F_2E_4	80% RDF with inline pc emitters
12	F_3E_4	60% RDF with inline pc emitters

F- Fertigation,   E - Emitters

Table 2. Fertigation schedule in tomato

Stage of Crop	Duration	Fertilizer Grade	Weekly scheduled per ha (kg)
Crop establishment	20 days	18:18:18	55.70
Crop development	30 days	18:18:18 46:0:0	31.25 16.25
Mid season	30 days	18:18:18 46:0:0	31.25 11.00
Late season	30 days	0:0:50	50.00

Table.3 Emission uniformity of emitters as affected by emitters and fertigation

Treatment	Online npc (E_1)	Online pc (E_2)	Inline npc (E_3)	Inline pc (E_4)	Mean
100% RDF (F_1)	93.51	99.04	89.78	94.66	94.25
80% RDF (F_2)	93.47	98.40	89.15	96.82	94.46
60% RDF (F_3)	93.52	97.82	88.67	95.71	93.93
Mean	93.50	98.42	89.20	95.73	94.21
	F	E	F×E	E×F	
SEm(±)	0.39	0.26	0.64	0.45	
CD (P=0.05)	NS	0.78	NS	NS	

F x E = Fertigation levels in same or different types of emitters
E x F = Emitter types in same levels of fertigation

Table.4 Effect of fertigation levels and emitter types on fruit yield (t/ha) of tomato (pooled over two years)

Treatment	Online npc(E_1)	Online pc (E_2)	Inline npc (E_3)	Inline pc (E_4)	Mean
	Fruit Yield, t/ha				
100% RDF (F_1)	57.14	59.82	55.22	57.72	57.47
80% RDF (F_2)	55.04	57.74	54.31	56.26	55.84
60% RDF (F_3)	46.48	48.64	45.78	47.62	47.13
Mean	52.89	55.40	51.77	53.87	53.48
	F	**E**	**F×E**	**E×F**	
SEm(±)	0.15	0.09	0.23	0.17	
LSD (P=0.05)	0.58	0.27	0.81	0.46	

Fig.1 (a) Variation of meteorological parameters during crop growth period in 2014
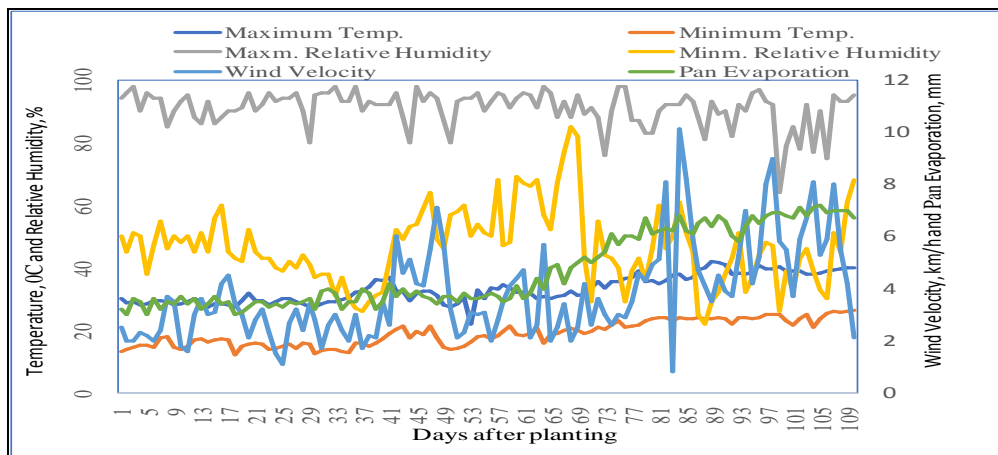

Fig.1(b) Variation of meteorological parameters during crop growth period in 2015
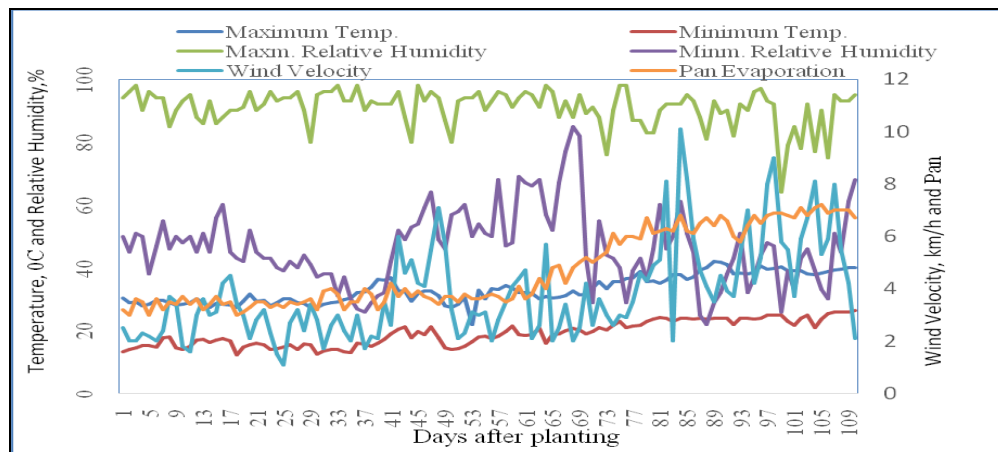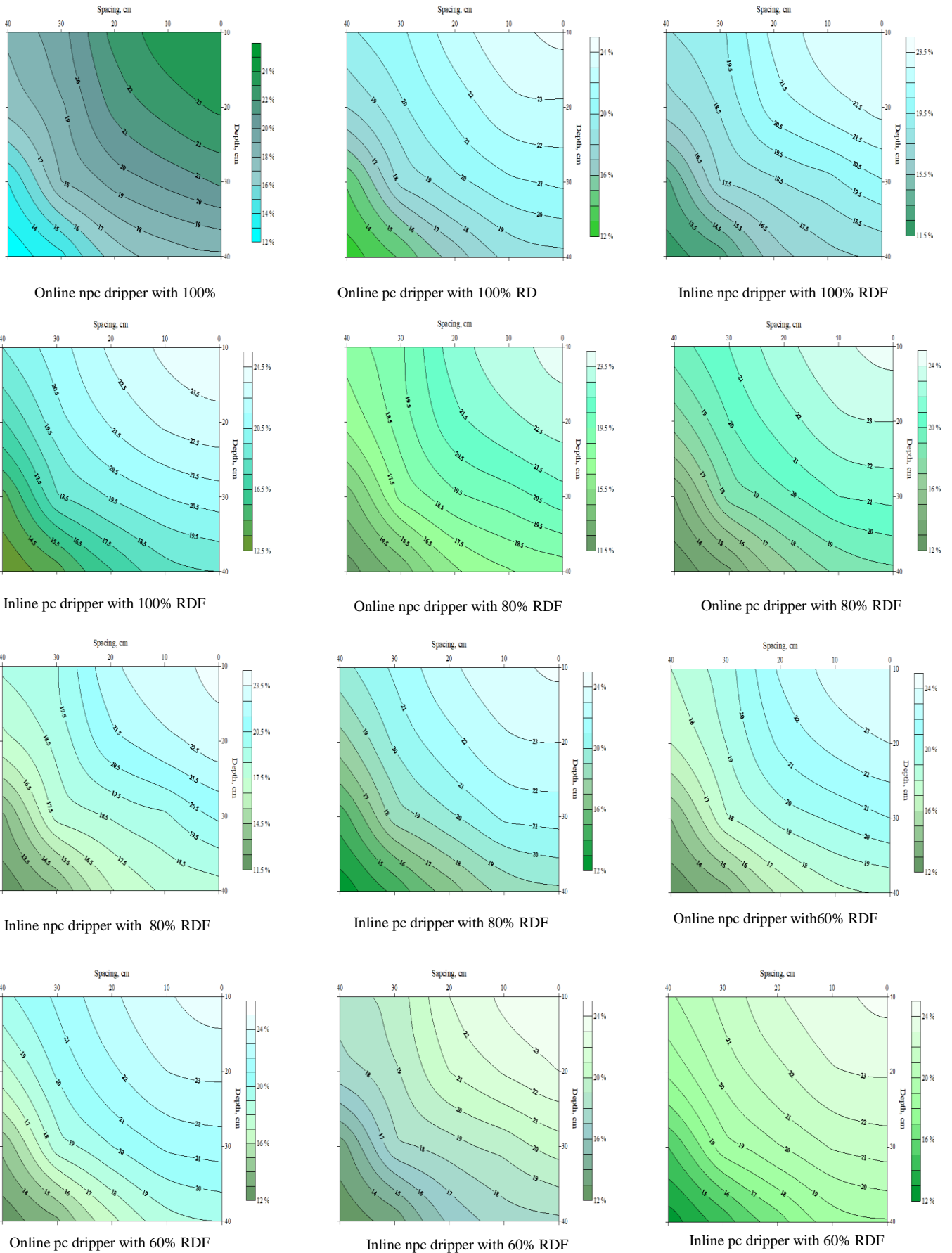
Fig.2 Soil moisture distribution under different emitters and fertigation level

Online npc dripper with 100%

Online pc dripper with 100% RD

Inline npc dripper with 100% RDF

Inline pc dripper with 100% RDF

Online npc dripper with 80% RDF

Online pc dripper with 80% RDF

Inline npc dripper with 80% RDF

Inline pc dripper with 80% RDF

Online npc dripper with60% RDF

Online pc dripper with 60% RDF

Inline npc dripper with 60% RDF

Inline pc dripper with 60% RDF

Among fertigation levels, 100% RDF fertigation recorded maximum fruit yield of 57.47 t/ha and proved significantly superior to 80 and 60% RDF levels (Table 4). Fertigation at 100% RDF level recorded 2.9 and 21.9% higher fruit yield over 80 and 60% RDF levels, respectively. The results are in conformity with findings of Rajput and Patel (2002), Hebbar *et al.,* (2004) and Rajaraman *et al., (*2013) who reported the maximum fruit yield of onion, tomato and okra, respectively at 100% RDF with drip irrigation at New Delhi, Bangalore and Thoppur (Tamil Nadu), respectively.

Among emitter types online pc proved the best with fruit yield of 55.4 t/ha and superior to all other emitter types. It recorded 2.8, 4.7 and 7.0 % higher fruit yield than inline pc, online npc and inline npc, respectively. The interaction effect of fertigation levels and emitter types on fruit yield of tomato was found significant. The 100% fertigation levels applied through online pc proved the best with fruit yield of 59.82 t/ha and proved superior to other combinations of fertigation levels and emitter types. In all fertigation levels, online pc proved the best with fruit yield of 59.82, 57.74 and 48.64 t/ha at 100, 80 and 60% fertigation levels (Table 4). The increase in yield for pressure compensating emitters was due to better emission uniformity of dripper which consequently resulted uniform application and uptake of water and fertilizer at root zone area of each plant.

Moreover, the pc emitters maintained higher soil moisture contents in the root zone of plant than npc which might have caused higher tomato yield.

In conclusions, the use of an appropriate drip irrigation system, fertigation, better emission uniformity and after all uniform soil moisture distribution give better yield of tomato. The emission uniformity among four types of emitters showed that online pc emitters recorded 5.3% more value over online npc emitters. Similarly inline pc emitters recorded 4.35% more emission uniformity value over inline npc emitters. It was observed that highest soil moisture content was recorded below emitters and decreased horizontally and vertically as distance from drippers increases. The maximum soil moisture content of 24.5% observed in case of treatment F1E4 followed by F3E2. The maximum fruit yield of 59.8 t/ha was also recorded in case of 100% fertigation through online pc emitters (F1E2). Hence, the drip fertigation through online pressure compensating emitters is recommended for tomato for maximum productivity.

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