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A comparative study between continuous and pulse drip systems on the yield of tomato (*Lycopersicon esculentum*) in sandy loam soil under the moist sub-humid condition

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ABSTRACT

A field study was carried out in a mid-central table agro-climatic zone (ACZ) to evaluate the soil moisture distribution and tomato crop yield in sandy loam soil using continuous and pulse drip irrigation. The response due to both continuous and pulse irrigation on waterfront advance, system efficacy, yield, and economics in emitters with variable capacities such as 2 lph continuous (T_1), 4 lph in both continuous and pulse (T_2, T_3), 8 lph in both continuous and pulse (T_4, T_5), and 16 lph in both continuous and pulse (T_6, T_7) was assessed. When compared to continuous treatment, the results reveal that the lateral movement of the waterfront in a pulse system is substantially less, regardless of the drippers providing equivalent discharge, and the reverse case was observed in a vertically downward direction. Throughout the crop growth period, pulse treatment outperformed continuous application, with T_5 exhibiting the highest crop growth and tomato yield, followed by T_4 and T_7. The cost economics revealed that T_5 had the highest benefit-cost (B:C) ratio (3.19), followed by T_4 (3.03), and T_7 (2.97) and T_1 has the lowest (2.76) value.

1. INTRODUCTION

Excessive use of limited water resources for over-irrigating major crops is a dangerous attempt by Indian farmers that may impede long-term sustainability of agricultural systems. Thus, water conservation and management are critical for the growth of a sustainable agricultural system that avoids land degradation, reduction in soil fertility, water quality, and destruction of other natural resources in an irrigated area. Because of water scarcity and the possibility of groundwater pollution from irrigated areas, increasing irrigation water use efficiency is crucial (Kar and Kumar 2015; Zhang *et al.,* 2017; Nicola *et al.,* 2020; Priyan K., 2021). Drip irrigation allows for precise water distribution based on crop water requirements, decreasing water losses by removing excess deep percolation and soil evaporation (Panigrahi *et al.,* 2010; Kapoor *et al.,* 2014; Besharat, 2018). Drip irrigation systems consist of tiny drippers that are either placed on surface or sub-surface zone and distributes water at a predetermined rate in a continuous or intermittent pattern. Numerous studies have revealed that in many crops, enhanced percolation below the effective root zone is the key response to continuous drip irrigation (Al-Ogaidi *et al.,* 2016; Li *et al.,* 2016; Wang *et al.,* 2018; Rank and Vishnu, 2021). In this context, intermittent water application-based pulse irrigation will increase field water management and irrigation system efficacy (Karimi *et al.,* 2022; Rawat *et al.,* 2022).

Pulsing drip irrigation is a modern irrigation method that comprises irrigation in a number of cycles that include an irrigation phase for a short time, followed by a resting phase for another short time, and so on until the appropriate amount of water is delivered (Jamei *et al.,* 2022; Rawat *et al.,* 2022). In both scenarios of with and without hysteresis effect (Elmaloglou and Diamantopoulos 2008), studies have demonstrated that pulsing can maintain high soil moisture in a small wetted soil volume, minimising percolation loss below the root zone (Bakeer *et al.,* 2009; El-Mogy *et al.,* 2012; Phogat *et al.,* 2012). The soil moisture variation depends on the difference in hydraulic potential between layers of soil, and some studies have indicated that pulse flow enhanced wetted width while decreasing wetted depth for the same discharge rate, lowering percolation loss and boosting leaching fraction (Phogat *et al.,* 2012; Badr and Abuarab 2013; Ismail, 2014).

In contrast to the majority of studies that concentrated solely on soil moisture dynamics and percolation loss in both continuous and pulse irrigation, a few studies focused on its application efficiency and cost economics. Thus, there is a need to assess and compare the soil moisture dynamics, system efficiency, and cost-economic analysis of both continuous and pulse drip systems for a specific plant, to obtain the detailed result of pulse drip irrigation and its optimum irrigation schedule for maintaining sustainable yield. The efficacy of continuous and pulse irrigation on moisture dynamics in the effective root zone, application efficiency, and cost economics in a tomato crop grown in sandy loam soil was studied in this research.

2. MATERIALS AND METHODS

Study Area

The study was conducted in the farmers' field of a village (latitudes of 20°85'N and a longitudes of 85°10'E) of Angul district, Odisha, India, which comes under the mid-central table agro-climatic zone (ACZ). The site has an elevation of 440 m and a hot and moist sub-humid climate, with an average annual rainfall of 1421 mm. The study location has sandy loam soil (81.2% sand, 5.4% silt, and 13.4% clay), which is the most common soil type in the mid-central ACZ. Table 1 gives the soil's physicochemical properties as measured before the experiment.

Table: 1
Physicochemical properties of soil of the experimental site

Soil properties	Values
Soil texture	Sandy loam
Sand (%)	81.2%
Silt (%)	5.4%
Clay (%)	13.4%
Field capacity	13.2%
Available water (AW) (%)	8.4%
Permanent wilting point	4.8%
Organic content (g kg^{-1})	0.62
pH	5.8
Bulk density (g cm^{-3})	1.53
EC (ds m^{-1})	1.2
Infiltration rate (mm hr^{-1})	26

Experimental Design

This comparative analysis was set up in the year 2018 in a randomized block design (RBD) which comprised of three replications and seven treatments. Irrigation was provided to each treatment independently by installing a regulating valve at each junction point of the lateral and the sub-main. Similarly, the release of water into the sub-main was controlled using pressure-regulated valves. The details of the treatments of the present work to irrigate tomato as a test crop (cv. *Chiranjibi Hyb.*) through drip irrigation are given in Table 2.

The experimental plot was separated into three plots by forming one-meter-wide ditches to create replicated plots, and those replicated plots were further divided into seven sub-plots to represent seven treatments. Small bunds of 30 cm × 20 cm × 15 cm (bottom width × top width × height) cross-section separated the replicated plots into appropriate treatment plots. The gross study area, net study area, and net treatment plot size were correspondingly 173.88 m^2, 113.4 m^2, and 5.4 m^2 (Fig. 1). Each treatment had 20 plants planted in two rows (10 plants in each row). Based on the spacing of the tomato crop as practised by the farmers, in each treatment plot, lateral spacing of 0.6 m and drippers were fitted in each line at emitter spacing of 0.45 m.

Determinants of the Study

Irrigation scheduling

The experimental plots were irrigated daily at a predetermined rate using the drippers designed as per the formula given in eq. 1.

$$\underset{(\text{lit day}^{-1}\text{plant}^{-1})}{\text{Daily irrigation needs}} = \frac{\text{Pan evaporation} \times \text{Pan coefficient} \times \text{Crop factor} \times \text{Canopy cover} \times \text{Spacing area}}{\text{Irrigation efficiency}} \quad ...(1)$$

Table: 2
Treatment details of the experiment

Treatments	Capacity of emitter	Irrigation technique	Continuous and pulse timings			
			Continuous irrigation time (min)	Pulse irrigation		
				Supply time (min)	Rest time (min)	Total time required (min)
T_1	2 lph	Continuous irrigation	30	-	-	-
T_2	4 lph	Continuous irrigation	15	-	-	-
T_3	4 lph	Pulse irrigation	-	15 (7.5-7.5)	15	30
T_4	8 lph	Continuous irrigation	7.5	-	-	-
T_5	8 lph	Pulse irrigation	-	7.5 (3.75-3.75)	22.5	30
T_6	16 lph	Continuous irrigation	3.75	-	-	-
T_7	16 lph	Pulse irrigation	-	3.75 (1.875-1.875)	26.25	30

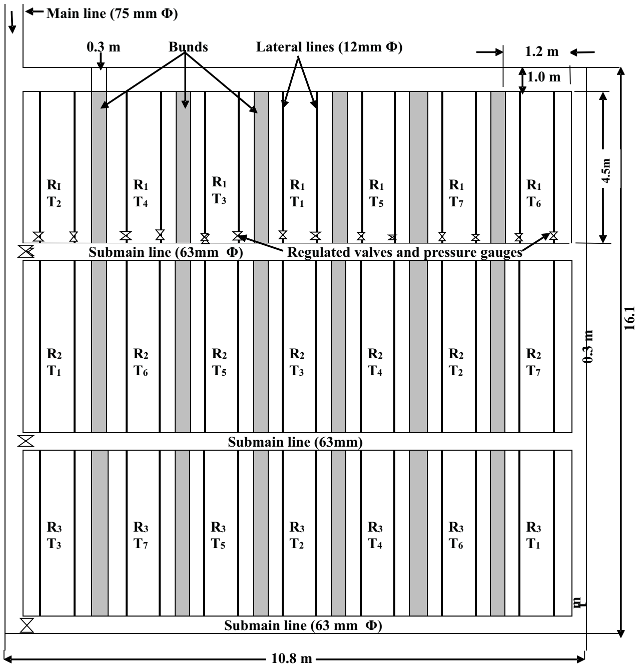

Fig. 1. Schematic diagram of designed experimental plot

The average maximum daily pan evaporation value for a period of ten years from a class A pan placed near a meteorological observatory was utilised in this equation to obtain pan evaporation data for this sub-humid climate. Deep percolation and surface runoff were both assessed as zero because the localised drip system delivered adequate water to just raise soil moisture to field capacity. At the control unit, a totalizing flow metre was attached to measure total flow dispersed to all replications in each treatment.

Measurement of soil moisture and water front advance

Soil moisture variation was measured by a digital moisture meter up to 30 cm soil zone below the ground surface during the entire period of the growing season of the crop. The thermo gravimetric moisture values were used to calibrate the digital moisture metre readings (Dastane, 1967). The movement of the waterfront as a function of time in both horizontal and vertical directions was observed in both continuous and pulse treatments to define the spread region under both conditions. Soil samples were taken to determine the moisture distribution pattern at a horizontal and vertical spacing of 5 cm from the water distribution points after each irrigation event. To measure deep percolation soil was dug up to the end of the crop root zone (60 cm) and wetting depth was measured in two dimensions across a range of distances by piercing the pointed tip of a 2 mm size GI wire.

Measurements of drip system efficacy

The uniformity characteristics must be determined for an adequate comparative study in continuous and pulse drip systems. The following are the uniformity parameters that were investigated in this experiment to test the flow hydraulics:

Emitter flow variation (q_{var})

The fluctuation of emitter discharge was calculated based on the pressure difference in the drip irrigation system, employing the relationship described by eq. 2 (Wu and Gitlin, 1974; Al-Mhmdy and Al-Dulaimy, 2018).

$$q_{var} = \frac{q_{max} - q_{min}}{q_{max}} \qquad ...(2)$$

Where, q_{var} = Emitter flow variation, q_{max} = Maximum emitter flow along the lateral line, q_{min} = Minimum emitter flow along the lateral line.

The discharge of each emitter in the lateral line was measured over a 15 min period using the catch can. For all lateral lines, the time of operation was chosen 15 min and kept constant. A mechanical pressure gauge was also used to check pressure drops at each emitter point.

Uniformity coefficient (U_c)

This coefficient shows the consistent application of water, implying that the variability in the water application to a plant in a subunit system. For standard design requirements, a system with a U_c of at least 85% is regarded suitable for irrigation. Only correctly designed emitters that deliver steady discharge to all emission points can achieve such a high U_c (Al-Amound, 1995).

The U_c, for emitter discharge rates was derived using Christiansen's (1942) equation, which was adjusted to reflect a percentage (Zhao *et al.,* 2012):

$$UC = 100\left[1 - \frac{\frac{1}{n}\sum_{i=1}^{n}|q_i - \bar{q}|}{\bar{q}}\right] \qquad ...(3)$$

Where, $\bar{q}$ = Mean emitter flow rate, n = Total number of emitters evaluated.

Emission uniformity (E_u)

E_u is parameter of a drip unit factor computed to measure flow variance by the ratio of the minimum discharge to the mean discharge (eq. 4) (Keller and Karmeli, 1974), similar to distribution uniformity of a sprinkler system (Barragan *et al.,* 2006).

$$E_u = 100\left[1 - \frac{1.27}{\mathrm{n}^{0.5}} \times \mathrm{C_v}\right] \times \frac{\mathrm{q_{min}}}{\mathrm{q_{avg}}} \qquad ...(4)$$

Where, E_u = emission uniformity, C_V = manufacturer's coefficient of variation, n = number of emitters per plant for trees and shrubs, q_{min} = minimum emitter discharge rate for the minimum pressure in the section.

Application efficiency (E_a)

The most critical factor influencing the agronomic and economic feasibility of an irrigation technique is its ability to deliver water equitably and adequately to the crop. In this sense, water E_a is a significant factor in determining whether or not a system's design and operation are optimal for irrigation water management. The irrigation E_a was evaluated using the following eq. 5 (El-Abedin 2006).

$$E_a = 0.9 \times E_u \qquad ...(5)$$

Where, E_u = Emission uniformity (%), E_a = Application efficiency (%).

Clogging ratio of emitters (CRE)

The CRE is an important indicator used in evaluating pulse drip irrigation efficacy (Mohanty *et al.,* 2016; Turkey *et al.,* 2020). A clogged emitter in a drip tape causes non-uniform water distribution and can sometimes be completely non-functional throughout the crop's growth season. The CRE is calculated by Abdelraouf (2012) using the eq. 6:

$$\text{CRE} = 1 - \eta \qquad ...(6)$$

Where, q_{used} = Average discharge for used emitters (lph), q_{new} = Average discharge for new emitters (lph), η = Efficiency of emitter (%); $\eta = \frac{q_{used}}{q_{new}}$

Biometric Characteristics and Yield

Plant height, taproot diameter, leaves area per plant, stem diameter at the base, fruit size, root volume and other biometric features of tomato crop were studied under various treatments. A screw gauge was used to measure the diameter of the stem at the base, the diameter of the taproot, and the size of the fruits (Adetan *et al.,* 2003). A leaf area metre was used to measure the leaf area of the tomato plant (Schwarz and Kläring, 2001). Each plant's root volume was measured by immersing the complete root system in a 1000 ml water filled measuring. The volume of water displaced is proportional to the root volume of the plant (Buttrose and Mullins, 1968). During the growing season, the weight of each of the aforementioned parameters, as well as the tomato fruit mass, were measured.

Economic Analysis

The cash inflow and outflow in the drip system with varied capacity emitters utilising continuous and pulse application methods were assessed using an economic analysis. The seasonal cost involvement was divided into fixed cost and variable cost. Seed, insecticides, fertilisers, and labour costs associated with field preparation, frequent weeding, and irrigation of treatment plots are among the variable costs. Based on the standard economic procedure, costs attached with repair, maintenance, operation and depreciation were assumed to be 10% of the drip system's total fixed cost inflow. Total discounted cash inflow was calculated as the product of output (tomato yield) and long-term averaged market price. The research also incorporates capital budgeting processes such as NPV calculation (eq. 7), which is a measure of the net return on the present drip system (Sharmasarkar *et al.,* 2001).

$$\text{NPV} = -\text{IC} + \frac{V_n}{(1+i)^n} + \sum_{j=1}^{n} \frac{P_j}{(1+i)^j} \qquad ...(7)$$

Where, *NPV* = Net present value, *IC* = Initial investment during the purchase of drip system with its accessories, *P* = Annual net cash flows in a year *j*, *V* = Salvage value at the end of the n year, *i* = Interest rate, *n* = Total life span of the system.

Using standard procedures, the payback period (PBP) and B:C ratio for each treatment were calculated after obtaining total cost inflow and outflow (Williams, 2012; Sinha *et al.,* 2017).

The procedure for calculation of pay-back period can be given by the eq. 8 (Raut *et al.,* 2014) such as:

$$P = \frac{I}{E} \qquad ...(8)$$

Where, *P* = Payback period of the drip system / project, *I* = Total investment in the system, *E* = Annual net income in rupees from the system.

$$B{:}C\ ratio = \frac{\sum_{j=1}^{n} \frac{B_j}{(1+i)^j}}{\sum_{j=1}^{n} \frac{C_j}{(1+i)^j}} \qquad ...(9)$$

B:C ratio was estimated using a simple formula (eq. 9) (Narayanamoorthy, 2005) which is as follows:

Where, *B* = Income in a year *j*, *C* = Cost involved in a year *j*, *I* = Interest rate per year, *n* = Total life span of the system

3. RESULTS AND DISCUSSION

Variation of soil moisture in crop root zone

Moisture content was measured in both horizontal and vertical directions to determine the variations in soil moisture caused by both continuous and pulse drip, and the results are shown in Table 3. Fig's. 2 and 3 illustrate the moisture distribution curves at two soil depths of 10 cm and 20 cm.

Varied irrigation treatments resulted in different vertical and lateral moisture distribution patterns. Moisture content was highest near and below the dripper point and fell vertically downward. At 10 cm and 20 cm soil depths, pulse irrigation gave higher soil moisture trend values than continuous irrigation. The underlying reason for this result is that the volume of water provided in the first pulse is

Table: 3
Variation of soil moisture in vertical and lateral direction under different treatments different treatments

Treatment	Horizontal distance, cm Vertical distance, cm	Soil moisture (dry wt. basis), % Distance from emitter point, cm -12	-11	-10	-9	-8	-7	-6	-5	0 (Emission point)	5	6	7	8	9	10	11
T_1	10					4.30	5.42	7.60	9.28	9.99	9.28	8.12	6.40	4.80			
	20						4.12	7.32	8.12	8.44	8.12	7.32	4.10				
T_2	10			2.10	3.26	4.40	6.97	9.28	10.52	10.80	10.52	9.28	6.97	4.42	3.32	2.20	
	20						6.11	7.55	8.47	9.27	8.47	6.72					
T_3	10				2.80	5.80	7.40	9.20	10.30	11.22	10.20	9.30	7.40	5.60	3.40		
	20					3.80	7.80	9.00	9.40	9.80	9.10	8.40	6.50	4.10			
T_4	10		2.20	4.40	5.80	7.40	9.20	10.00	10.40	11.02	10.60	9.80	9.10	80	5.50	4.50	2.60
	20					4.50	6.70	8.20	9.40	10.30	9.80	8.60	6.80	5.20	2.80		
T_5	10			5.6	6.4	8.6	10	10.4	10.8	11.8	11.1	10.8	10.2	9.5	6.00	4.6	
	20					6.6	8.4	9.4	9.8	10.8	9.8	9.1	7.6	6.4			
T_6	10	0.9	1.8	2.4	5.4	7.3	8.2	8.9	10.4	12.2	10.8	9.1	8.4	7.4	5.3	2.4	1.2
	20				3.1	5.2	7.4	8.4	9.2	10.4	9.4	8.4	7.2	5.6	3.3		
T_7	10					6.8	8.8	11.6	12.4	12.6	12.4	11.2	8.2	6.2			
	20					6	6.2	8	8.6	10.6	8.6	8	6.4	5.2			

$CD_{0.05} = 0.1484$, SEM ± = 0.0478

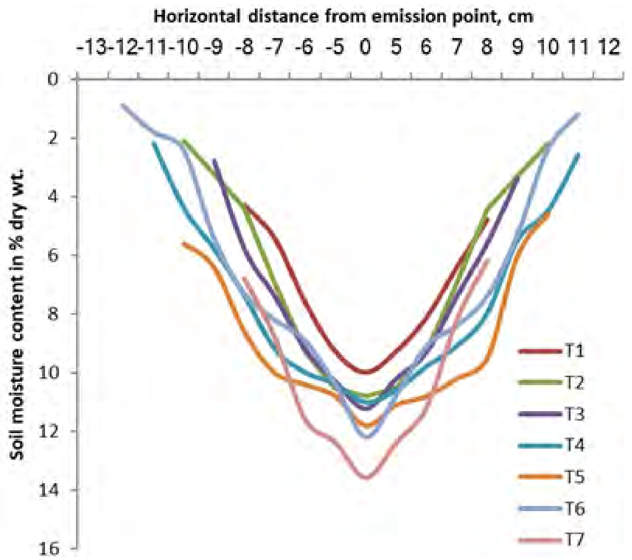

Fig. 2. Moisture variation at 10 cm depth in soil under different treatments

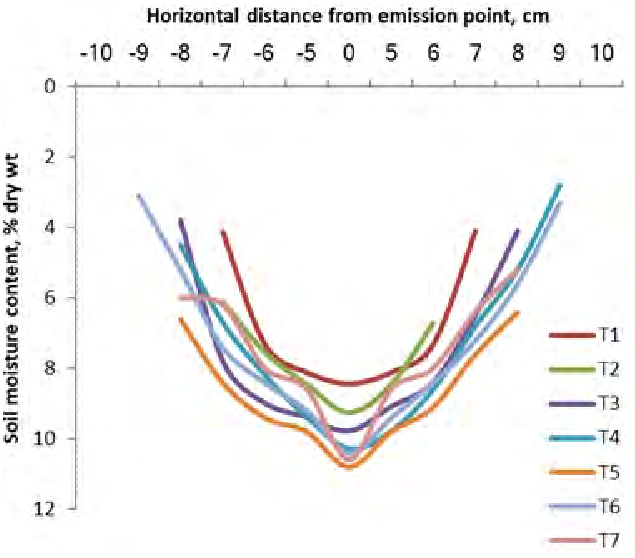

Fig. 3. Moisture variation at 20 cm depth in soil for all treatments

moved horizontally and vertically in the soil beneath during the off period, resulting in increased moisture in the soil after the second pulse irrigation. T_5, *i.e.,* pulse irrigation through an 8 lph emitter, resulted in better moisture distribution in the soil than the other treatments, as shown in Fig's. 2 and 3.

Variation of Wetting Front Advance

The wetting front in both lateral and vertical dimensions differed among the treatments due to differences in discharge rate and mode of application (Table 4). Regardless of the capacity of the drippers delivering the same quantity of water, the lateral movement in the pulse

Table: 4
Wetting front advance in lateral and vertical direction with different treatments

Treatments	Horizontal → distance, cm Vertical depth, cm ↓	-13	-12	-11	-10	-9	-8	-7	-6	-5	0 (Emission point)	5	6	7	8	9	10	11	12
T_1					0	10.5	20.5	22.8	28	35	38	34	24.5	20.5	12.5	0			
T_2			0	7.5	11	18	22.5	26	27.5	32.5	34	31	23	20.5	15	12.5	0		
T_3				0	12	20	25.5	25	27.5	30	32	30	27.5	25.5	21.5	15	0		
T_4			0	7	11	21	22.5	24	25.5	26	27	25.5	24.5	23.5	22	21	12.5	7	0
T_5				0	15	25	27.5	28.5	29	29.5	30	29	28.5	28	26.5	23.5	15	0	
T_6		0	5	9	15	22	22.5	24	24.5	25	26	25	24.5	23.5	23	20.5	16	8.6	0
T_7				9.6	12.50	15.80	18.5	22.5	25	27	30	29.5	27.5	25	20	17.40	13.80	0	

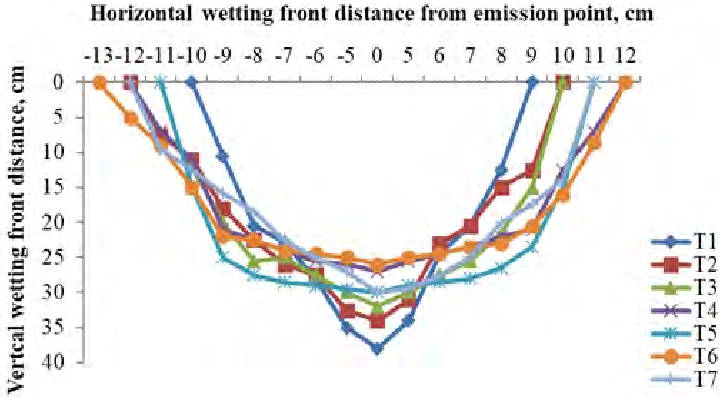

Fig. 4. Variation of wetting front advance for all treatments

system is smaller than that in the continuous irrigation system, and the reverse is true in a vertically downward direction (Fig. 4). At low discharge rates against gravity, continuous water application creates a capillary predominance effect, which becomes more pronounced at increasing discharge rates. T_5 produced a superior environment with an optimal distribution of moisture in the soil, resulting in improved root growth and, as a result, production, among the treatment.

Effect of irrigation techniques on emitter flow and pressure relationship

The flow in the drip system was spatially varied, with a reduced discharge from the first emitter to the emitter at the terminal. The study also revealed that flow variations are the same whether an emitter discharges water either continuously or using a pulse approach. Furthermore, the maximum pressure variation was recorded in T_1, whereas pressure variation for continuous and pulse flow remained constant in other treatments. T_5 had the lowest pressure variance, with a supply time of 7.5 min and an off time of 22.5 min.

The operating pressure and design of emitters all have a significant impact on emitter flow rate. Fig. 5 depicts the observed flow velocities and pressures under various treatments. The above observed values were fitted in the form of a power function equation *i.e.* eq. 10 (Karmeli and Keller, 1975).

$$q = ch^x \qquad ...(10)$$

Where, q is the discharge rate in lph, h is the pressure head in kg cm^{-2}, c is the flow coefficient, and x is the pressure head exponent. It is found that the flow coefficient value of a specific emitter is equal to or very close to the discharge rate of that emitter. The exponent of pressure head 'x' for each emitter was found to be between 0.546 and 0.520, indicating that the flow is turbulent (Fig. 5).

Effect of irrigation techniques on drip hydraulic performance indices

For various emitters and treatments, the U_C, E_u, and E_a were calculated using eq's 3, 4 and 5 and the results are presented in Table 5. T_5 had the highest U_C (98.5%), E_u (96.8%), and E_a (87.12%), while T_1 had the lowest. The U_C, E_u, and E_a of all emitters, whether they

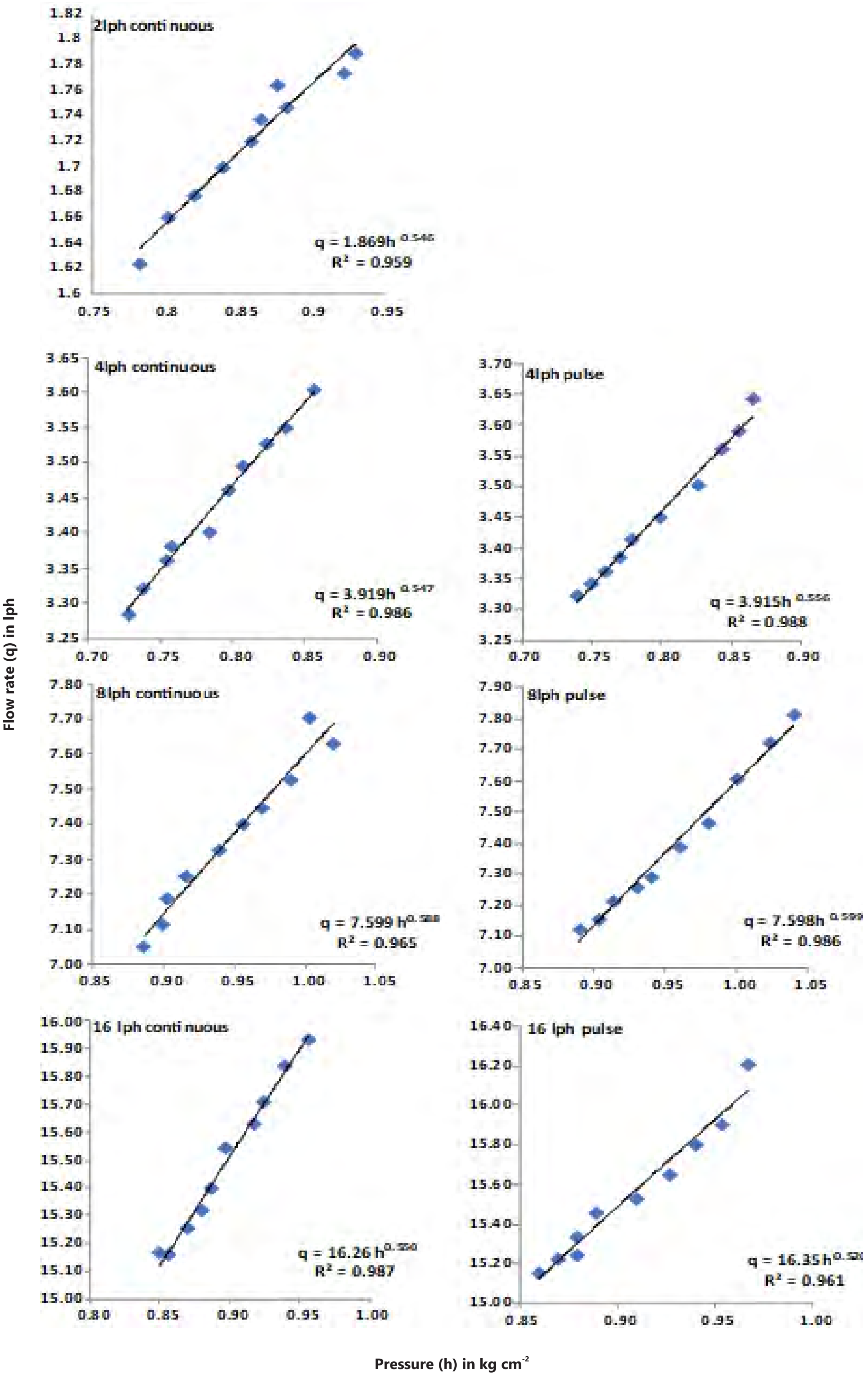

Fig. 5. Emitter flow variation as affected by pressure

Table: 5
Uniformity coefficient, emission uniformity and application efficiency for various treatments

Treatments	Uniformity coefficient, U_c (%)	Emission uniformity, E_u (%)	Application efficiency, E_a (%)
T_1	97.00	91.20	82.08
T_2	96.90	91.90	82.71
T_3	97.40	92.30	83.07
T_4	98.20	95.70	86.13
T_5	98.50	96.80	87.12
T_6	97.30	92.90	83.61
T_7	97.60	93.50	84.15

distribute water continuously or in pulses, are greater than 90%, according to the evaluation. Among all treatments, pulse application of water through 8 lph (T_5) performed better than the other drip systems, giving the equivalent amount of water to the crop.

The CRE was calculated for various and the results are presented in Fig. 6. CRE reduced as the rate of water application increased up to T_5, then rose in T_6 and T_7. The same emitter used both for continuous and pulse system with volume of water application remaining same showed a lower CRE value in pulse application over continuous one. It might be due to the turbulence caused in the flow channel by pulse approach (cycle on-off), preventing suspended particles from accumulating in flow channels and emitter outlets. The CRE for T_6 and T_7 is higher than for T_4 and T_5. The occurrence of turbulence generation for short period of time inside the emitter flow route in case of T_6 and T_7 might have been insufficient to avoid the accumulation of suspended particles and as a result when water was delivered in continuous and pulse techniques through a 16 lph emitter, a high CRE was found.

Effect of Irrigation Techniques on Yield Components

Different treatments radically affected biometric features such as root volume, number of leaves, stem diameter, plant height, root diameter at the base, fruit weight and fruit diameter (Table 6). For all the vegetative parameters, the maximum values were obtained in T_5. T_5 treatment showed the maximum yield (40533 kg ha^{-1}), followed by T_4 (39217 kg ha^{-1}) and T_7 (38618 kg ha^{-1}) treatments. The performance of pulse drip irrigation was found better over continuous drip irrigation in all cases.

With more shut-off phases in the pulsed treatment, applied water had more time to diffuse laterally around the emission point and vertically downward in the plant's effective root zone, providing uniform soil moisture regimes in soil layers and improved vegetative growth of plants. An optimal break up of dripper application time and its rest time can improve their efficacy in supplying favourable soil moisture distribution in the soil, resulting in higher yield.

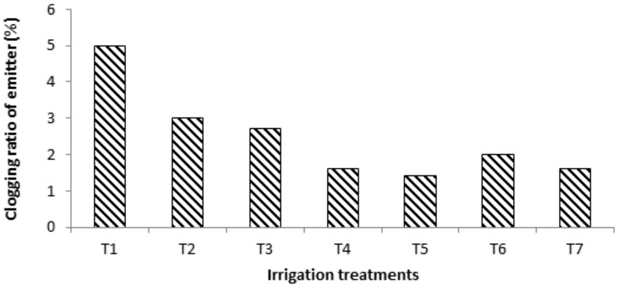

Fig. 6. Effect of different treatments on clogging ratio of emitters

Cost Economics

Table 7 shows the comprehensive cost economics for tomato crop cultivation with drip irrigation systems for various treatments for of 1.0 ha unit area. According to the analysis, the NPV values differ depending on the treatments, with the highest NPV value observed in treatment T_5 (₹ 12,47,792) and the lowest in treatment T_1 (₹ 10,05,569). A similar result was observed in the B:C ratio also. The calculated PBP values showed that T_5, *i.e.,* irrigation to tomato crop with two pulses through 8 lph emitter, resulted in the shortest PBP (2.90 years), followed by T_4 (3.05 years) and T_7 (3.12 years).

4. CONCLUSIONS

The results of this experiment show that intermittent irrigation techniques based on discharge pulses followed by a rest period have the potential to improve drip system performance in sandy loam soil. Among the treatments, T_5 provided a superior environment with an optimal distribution of moisture in the soil, having more than 25 cm of lateral and vertical spread, resulting in improved root growth and, as a result, production. When compared with the continuous drip system, pulsed drip outperformed in all aspects as T_5 had the highest U_C (98.5%), E_u (96.8%), and E_a (87.12%), while T_1 had the lowest. In 4 lph, 8 lph, and 16 lph emitters, the pulse approach enhanced tomato yield by 1.07%, 3.35%, and 2.32%, respectively, over continuous irrigation thus, maintaining a uniform soil moisture regime in the crop root zone, optimising system hydraulic effi-

Table: 6
Biometric characteristics of tomato crop under different treatments

Treatments	Replication	Stem diameter (cm)	No. of leaves plant^{-1} (nos.)	Leaf area (cm^2)	Root volume (cm^3)	Max. root diameter (cm)	Fruit diameter (cm)	Fruit wt. (gm)	Ht. of tree (cm)
T_1	R1	1.90	180	34.35	27.00	0.45	4.50	63.50	75.00
	R2	1.85	175	34.00	27.20	0.50	4.20	63.00	74.80
	R3	1.80	185	35.20	28.10	0.55	4.10	62.90	75.20
	Mean	1.85	180	34.58	27.43	0.50	4.27	63.13	75.00
T_2	R1	2.04	192	35.91	31.00	0.65	4.80	63.96	77.00
	R2	1.97	190	35.00	30.90	0.60	4.75	63.50	77.00
	R3	2.15	194	34.50	30.50	0.55	4.60	63.00	76.60
	Mean	2.04	192	35.14	30.80	0.60	4.72	63.49	76.87
T_3	R1	2.05	193	46.17	30.00	0.65	4.85	65.00	78.00
	R2	2.01	191	47.30	30.95	0.70	4.90	64.95	78.4
	R3	2.07	195	46.25	31.00	0.75	4.80	65.10	77.00
	Mean	2.04	194	46.57	30.65	0.70	4.85	65.02	77.80
T_4	R1	2.10	198	71.22	35.00	1.00	5.30	66.92	85.00
	R2	2.13	196	71.65	35.00	0.95	5.30	67.01	84.00
	R3	2.15	198	70.00	34.90	1.00	5.31	67.05	85.00
	Mean	2.13	197	70.96	34.96	0.98	5.30	66.99	84.67
T_5	R1	2.23	200	76.36	36.00	1.20	5.42	67.01	86.00
	R2	2.20	201	75.55	35.20	1.00	5.45	67.15	86.20
	R3	2.24	200	75.9	35.00	0.98	5.48	67.4	86.00
	Mean	2.22	200	75.94	35.40	1.06	5.45	67.18	86.07
T_6	R1	1.80	190	56.11	34.00	0.80	5.01	65.31	80.00
	R2	1.75	192	56.50	33.01	0.70	5.10	65.35	80.50
	R3	2.00	190	55.00	32.00	0.85	4.95	65.75	80.00
	Mean	1.85	190	55.87	33.00	0.78	5.02	65.47	80.17
T_7	R1	2.00	194	56.32	34.50	0.95	5.21	66.22	80.50
	R2	2.10	193	56.00	34.70	1.00	5.23	66.27	81.00
	R3	2.11	196	55.85	34.10	0.85	5.25	66.32	82.00
	Mean	2.07	194	56.06	34.40	0.90	5.23	66.27	81.17
$CD_{0.05}$		0.12	3.56	1.20	1.14	0.12	0.18	0.53	1.04
SEM±		0.03	1.15	0.35	0.33	0.04	0.05	0.15	0.30

Table: 7
Computed cost economic parameters under different treatments

Treatments	Fixed cost (₹)	Variable cost (₹)	Present worth variable cost (₹)	Total cost out flow (₹)	Total discounted cash inflow (₹)	NPV (₹)	B:C ratio (₹)	Payback period (₹)
T_1	355506	304098	216908	572414	1577984	1005569	2.76	3.39
T_2	355506	302417	215693	571199	1607764	1036565	2.80	3.32
T_3	355506	302417	215693	571199	1633153	1061954	2.85	3.36
T_4	355506	301932	215343	570849	1732038	1167395	3.02	3.07
T_5	355506	301932.	215343	570849	1818641	1247792	3.17	2.91
T_6	355506	301678	215159	570665	1693922	1123257	2.86	3.34
T_7	355506	301678	215159	570665	1732037	1161372	2.96	3.16

ciency, and offering a better B:C ratio. The performance study of pulsed drip irrigation shows that it improves drip system efficacy and crop output in field crops, particularly vegetable crops, which is not possible in continuous drip irrigation in sandy loam soils and farmers can choose this water management approach to increase yield while ensuring optimum water conservation, leading to sustainable agriculture.

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