Design, construction and evaluation of low pressure and low cost drip irrigation system

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Abstract: A manually operated low pressure low cost (LPLC) drip system was developed from locally available materials using KB pipes, KB pressure treadle pump, pressure drum with microtubes and medical infusion set. The field experiments were conducted and effect of various independent parameters such as vegetative growth, hydraulic performance, crop water requirements, water use efficiency, and cost economics were evaluated on different aspects for tomato and broccoli. The developed system has payback period of one season only with benefit to cost (B/C) ratio of 1.59 to 5.31. Thus, appropriate, affordable, divisible, accessible, low operation and maintenance cost, user friendly LPLC drip irrigation system is a good alternative for small land holders.

Keywords: LPLC drip irrigation system, medi-emitter, divisible, vegetative growth parameters

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1 Introduction

India possesses 160 million ha of cultivated land (second largest in the world) and more than 70 percent of its population depends on agriculture. Out of 320 million work force of India, 170 million (53 percent) are employed in agriculture. The present productivity of food grains of irrigated farm area is 2-3 t/ha only as compared to 4-6 t/ha on research farms. Food production has become almost stagnant whereas the population of the country has exceeded 1,000 million people. Agriculture is by far the biggest user of water accounting for more than 70 percent of water utilization worldwide and 90 percent of water utilization in the developing countries. Irrigation is the largest consumer of fresh water. Therefore the aim should be to get optimal productivity per unit of water. Scientific water management, farm practices and drip irrigation method should be adopted wherever feasible (Alam and Kumar, 2001).

The drip systems require intensive capital due to sophisticated technology. Therefore, it is beyond the capacity of the most farmers in India. If the drip system could be made affordable and within the reach of small and marginal farmers, it will definitely increase the productivity and income of the farmers and also, conserve the scarce precious water resources of the country.

International Development Enterprises (IDE) has developed a low cost drip irrigation system, which has been extensively field tested to advance this technology accessible to small and marginal farmers. It has working head 0.5-3.0 m with 73-84 percent distribution uniformity (Polak et al., 1997).

The objectives of present investigation were to develop and evaluate low pressure low cost (LPLC) drip irrigation system made from locally available materials and that would be adoptable and affordable for small land

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holders. The overall view of the system is shown in Figure 1.

Figure 1 Overall view of experimental site

2 Materials and methods

The field experiments were conducted in 2008-2009 at Rajasthan Collage of Agriculture, Udaipur on level ground and 0.5 percent up slope for tomato and broccoli. The vegetative growth parameters, hydraulic performances, crop water requirements, water use efficiency, and cost economics were evaluated. The system was operated under 6 m pressure head, and discharge of emitters was determined. The application time was calculated on the basis of K_c and pan evaporation (35 years weekly climate normal during growth period of vegetable crops from hydro-meteorological observatory, RCA, Udaipur, 2008).

Sprouting broccoli (*Brassica olreacea* L. var. italica) cv. Aishwarya (F_1 - Hybrid) and tomato (*Lycopersicon esculentum* Mill) cv. Dev variety were used for trials. The system incorporated medical infusion set as emitters, hereafter referred to as medi-emitters. Emitters clogging which is common menace with drip systems were controlled by weekly addition of lime in storage tank. Treatments combinations were:

T1: Broccoli grown on level ground with medi-emitters

T2: Tomato grown on 0.5 percent up slope with medi-emitters

T3: Tomato grown on level ground with microtubes

T4: Broccoli grown on 0.5 percent up slope with microtubes

The experiment was laid out with four treatments with randomized block design (RBD). Subplot area was 156.25 m^2, soil type was silty-clay, area to be wetted as a percentage of total area was taken as 70 percent, crop spacing was 0.45 m × 0.60 m. The water source was at the center of the field, spacing of dripper along the lateral was 0.45 m, and spacing of laterals was 1.20 m. The Hazen William constant for LLDPE pipes was taken as 140, internal diameter of lateral was 20 mm, internal diameter of submain was 26 mm, length of microtubes (ID = 0.9 mm) and medical infusion (ID = 3 mm) was 0.45 m with maximum pan evaporation 4.7 mm/d in each treatment. Each subplot was comprised of 21 rows with 566 plants in each row from which 5 were selected randomly as observational plants. Paired rows planting pattern was adopted. Row to row and plant to plant spacing was 0.60 m and 0.45 m, respectively.

2.1 Design of Low Pressure Low Cost (LPLC) drip irrigation system

The system was designed on the basis of climatologically data, constructed with locally available materials and components available at IDEI, Ahmedabad. The drip system was designed as a paired-row planting system and fabricated with KB pipes, KB pressure treadle pump with pressure drum 200l (source). The William-Hazen formula was used for calculation of head loss.

Pan evaporation method was used for estimating crop water requirement (Mane et al., 2006).

Volume of water required

$$V = \frac{CA \times PE \times P_C \times K_C \times PWA}{E_U} \tag{1}$$

Where: V is Volume of water required, l/day/plant; CA is crop area, m^2; PE is maximum pan evaporation, mm/d; P_C is pan coefficient; K_C is crop coefficient; PWA is Percentage wetted area; E_U is emission uniformity, decimal.

2.2 Hydraulic characteristics of LPLC drip

Hydraulic design affects both system uniformity and spatial uniformity of a micro-irrigation system. The hydraulic performance parameters were used to evaluate drip systems. The systems were operated under 6 m pressure head. The discharge of emitters and its hydraulic parameters were evaluated. Irrigation was scheduled daily. The discharge of the emitters was measured by selecting the initial point, point after 1/3, 2/3 run and at last emitters on the corresponding laterals in the subplot of 4 laterals. The sixteen data collected were used for hydrological and uniformity analysis.

Hydraulic characteristics of the LPLC drip were evaluated using discharge and operating head. Emitters flow variation and pressure variations for drip irrigation is based on submain, lateral line hydraulics, which takes the form given by (Wu, 1975 and Wu, 1997). The emitter flow variation is given by

$$q_{\text{var}} = \frac{(q_{\max} - q_{\min})}{q_{\max}} \tag{2}$$

Where: q_{var} is emitter flow variation; $q_{\max}$ is maximum emitter flow; $q_{\min}$ is minimum emitter flow.

The pressure variation is given by

$$h_{\text{var}} = \frac{(h_{\max} - h_{\min})}{h_{\max}} \tag{3}$$

Where: h_{var} is emitter pressure variation; $h_{\max}$ is maximum pressure in line; $h_{\min}$ is minimum pressure in line.

There are four commonly used parameters for micro-irrigation evaluation (Wu, 1997).

1) Christiansen uniformity coefficient

$$CUC = \left[1 - \frac{\frac{1}{n}\sum_{i=1}^{n}|q_i - \bar{q}|}{\bar{q}} \right] \times 100\% \tag{4}$$

Where: CUC is the Christiansen uniformity coefficient; $\bar{q}$ is the mean emitter flow discharge and q_i is emitter flow discharge.

2) Coefficient of variation

$$C_v = \frac{S}{q} \tag{5}$$

Where: C_v is the coefficient of variation of emitter flow and S is the standard deviation of the emitter flow.

3) Statistical uniformity coefficient

$$UCS = 1 - C_v \tag{6}$$

Where: UCS is the statistical uniformity coefficient.

4) Emitter flow variation, q_{var}

Wu and Gitlin (1973) used following equations for application efficiency in drip irrigation system.

$$Ea = \left(\frac{q_{\min}}{q_{\text{avg}}}\right) \times 100\% \tag{7}$$

Where: Ea is application efficiency, %; $q_{\min}$ is minimum emitter flow rate, L/h; q_{avg} is mean flow rate, L/h.

Keller and Karmeli (1974) suggested two parameters for evaluation of emission uniformity "EU" which is a measure denoting the degree of uniformity of water application to the field. They are EU_f and EU_a.

$$EU_f = \left(\frac{q_n}{q_a}\right) \times 100\% \tag{8}$$

$$EU_a = 100 \times \left[\frac{Q_{\min}}{Q_{\text{avg}}} + \frac{Q_{\text{avg}}}{Q_x}\right] \tag{9}$$

Where: EU_f is Field emission uniformity; EU_a is Absolute emission uniformity; q_n is The average of lowest 1/4 of the emitter flow rate, L/h; q_a is the average of all emitter flow rates, L/h; q_x is the average of the highest 1/8 of the emitter flow rate, L/h.

Keller and Karmeli (1974) calculated design emission uniformity by the following formula.

$$EU_d = 100\left(1 - 1.27\frac{V_m}{N_e^{0.5}}\right)\frac{q_{\min}}{q_{\text{avg}}} \tag{10}$$

Where: EU_d is design emission uniformity, %; V_m is manufacturing coefficient of variation; N_e is number of emitters per plant; $q_{\min}$ is minimum emitter flow rate, L/h; q_{avg} is average emitter flow rate, L/h.

2.3 Measurements

Soil water content, vegetative growth parameters, hydraulic performances, crop water requirements, water use efficiency, and economic profitability were used to evaluate the overall performance of each treatment. Soil water content (SWC) measurements were taken throughout the experiment at 30 cm and 60 cm depth of soil profile using AIC tensiometer before irrigation. Gravimetric method was used for calibration of tensiometer. A soil-water retention curve was prepared from different soil samples having different tensiometer readings.

Vegetative growth parameters include four biometric parameters, above ground biomass (AG biomass), fruit mass (FM), crop residue (CR), and root mass (RM). They were measured at the time of harvest. The fresh and dry weight of each aforementioned biometric parameter was measured. The water use efficiency (WUE) is one of the best tools for evaluating the performance of different irrigation treatments. WUE was calculated as the ratio of the crop yield (t/ha) to the total seasonal irrigation water applied (cm) during the field growing season.

The economic viability of each irrigation treatment was calculated assuming each treatment was operated on a 156.25 m^2 (566 plants). The total amount of fruit mass produce was determined by average yield of randomly selected five plants within the plot and price based on market rate.

3 Results and discussion

3.1 Moisture content

Daily soil moisture was measured before irrigation at 30 cm and 60 cm depth of soil profile using a tensiometer. Ten cbar represents the field capacity of soil. Fitted equation is given below

$$\%MoistureContent = 39.57(cbar)^{-0.2398} \quad (11)$$

Soil water content at field capacity was found to be 22.78%. Daily drip irrigation maintained soil moisture near field capacity in 30 cm and 60 cm depth of soil profile.

3.2 Design of LPLC drip irrigation system

The details of various design parameters are given in Table 1.

Table 1 Design evaluation of LPLC drip irrigation system

S. No.	Data	Treatments			
		T1	T2	T3	T4
1	Topography of field	level	0.5% up slope	level	0.5% up slope
2	Crop type	Broccoli	Tomato	Tomato	Broccoli
3	Crop factor, K_c	1.05	1.15	1.15	1.05
4	Type of dripper	Medi-emitters	Medi-emitters	Micro-tubes	Micro-tubes
5	Average discharge of emitter/L • h^{-1}	2.29	2.11	1.05	0.86
6	Irrigation time/h	0.30	0.38	0.71	0.85
7	Distribution uniformity, EU_f/%	94.65	89.70	95.79	89.08
8	Head loss in lateral/cm	0.50	0.43	0.12	0.08
9	Head loss in submain/cm	14.04	11.94	3.30	2.30
10	Total head loss from lateral and submain/cm	14.54	12.37	3.42	2.38
11	Head loss from operating head 6 m/%	2.42	2.06	0.57	0.40

Note: NB: 26 mm (ID = 20 mm) and 32 mm (ID = 26 mm); KB pipes were only available at IDE, Ahmedabad.

3.3 Head-discharge relationship

The variation in average discharge for micro-tubes and medi-emitters at different pressure head for different treatment are graphically presented in Figure 2. It was observed that as head increased by 1 m, average discharge increased by 37.91%, 13.15%, 9.25% and 6.22% in case of T1, T2, T3 and T4 respectively. A similar trend was also reported by (Magar et al., 1985 and Firake et al., 1992) observed that 75% increase in pressure head increased the discharge through micro-tubes by 60%. Discharge variation is more in case of medi-emitters compared to micro-tubes due to larger diameter. Over a wide range of discharge of emitters flow estimation can be used (Keller and Karmeli, 1974).

$$q = kH^x \quad (12)$$

Where: q is emitter discharge, L/h; k is constant of proportionality; H is working pressure head, m; x is emitter exponent, which characterizes the flow regime.

A linear regression of ln (H) on ln (q) yielded the values for emitter exponent (x) and k. Flow through micro-tubes was turbulent due to smaller diameters where as flow through medi-emitters was laminar due to larger diameters.

The equations for average discharge of micro-tubes and medi-emitters at various pressure heads are presented in Table 2.

Table 2 Fitted equations for different treatments

Treatments	Fitted Equation	R^2
T1	$q = 0.1402h^{1.53}$	0.9310
T2	$q = 0.4544h^{0.86}$	0.9962
T3	$q = 0.4814h^{0.44}$	0.9954
T4	$q = 0.4064\text{h}^{0.42}$	0.9831

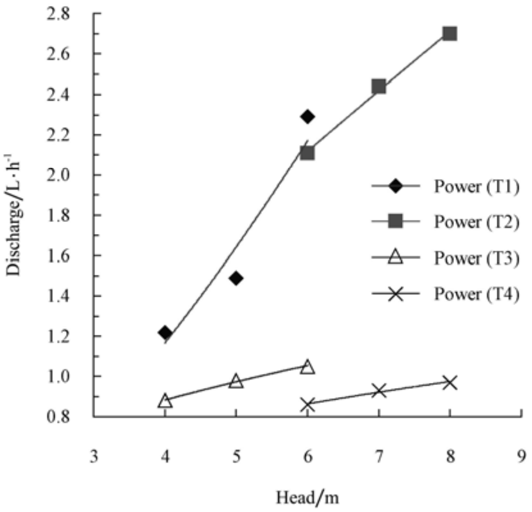

Figure 2 Average discharge under treatments (T1 to T4) with different heads

3.4 Irrigation efficiencies

Irrigation efficiencies of the systems are shown in Table 3.

The hydraulic design and component selection of the affordable LPLC drip system offers satisfactory hydraulic performance. Discharge variation and pressure variation was more in case of medi-emitter compared to micro-tubes. Variation in discharge was low and uniformity was high at high head. Uniformity tested under 4-8 m head, q_{var}, h_{var}, C_v, *UCS*, *CUC* and EU_d found in the range of 8.58% to 24.29%, 16.36% to 48.84%, 0.0945 to 0.1675, 86.15% to 90.82%, 85.69% to 92.44% and 58.33% to 75.17% respectively meeting ASAE standards.

Table 3 Irrigation efficiencies of LPLC drip irrigation system

Treatments	Head/m	q_{var}/%	h_{var}/%	EU_f/%	EU_a/%	*Ea*/%	C_v	*UCS*/%	*CUC*/%	EU_d/%
T1	4	24.29	48.84	83.13	80.98	70.78	0.1385	86.1526	88.6317	58.3341
	5	17.51	36.17	89.78	84.33	76.38	0.1363	86.3727	89.1122	63.1627
	6	16.60	33.93	94.65	84.74	81.08	0.1218	87.8232	90.1240	68.5405
Avg	5	19.47	39.65	89.19	83.35	76.08	0.1322	86.7828	89.2893	63.3458
T2	6	20.74	42.00	89.70	82.42	76.73	0.1270	87.2997	89.7276	64.3554
	7	17.73	34.48	93.29	82.94	77.33	0.1249	87.5094	90.0652	65.0634
	8	10.11	21.67	93.68	88.07	79.94	0.1074	89.2599	90.7703	69.0401
Avg	7	16.19	32.72	92.22	84.48	78.00	0.1198	88.0230	90.1877	66.1530
T3	4	13.76	28.89	91.35	87.73	80.89	0.1149	88.5103	91.7524	69.0876
	5	11.48	22.00	93.77	88.29	82.05	0.0945	90.5549	92.1337	72.2090
	6	8.58	16.36	95.79	90.32	85.08	0.0918	90.8236	92.5857	75.1666
Avg	5	11.27	22.42	93.64	88.78	82.67	0.1004	89.9629	92.1573	72.1544
T4	6	17.02	33.33	89.08	82.30	70.99	0.1675	83.2513	85.6894	55.8878
	7	15.32	30.36	90.63	86.89	80.13	0.1140	88.6041	91.4378	68.5323
	8	11.88	23.33	94.68	87.61	82.04	0.0988	90.1160	92.4441	71.7378
Avg	7	14.74	29.01	91.46	85.60	77.72	0.1268	87.3238	89.8571	65.3860

3.5 Vegetative growth parameters

The details of biometric parameters are presented in Table 4. Treatments T1 and T3 performed better than T2 and T4 in respect to vegetative growth parameters. From the data of growth attributes (plant height, number of leaves, stem girth, ground coverage, number of fruit, number of branch/secondary head, leaf area, leaf area index, root growth, yield and quality of fruit, wet and dry matter content) it was concluded that T1 and T3, performed better than T2 and T4. The mean yield of fruit kg/plant of broccoli and tomato in treatment T1 (1.01 kg) followed by T4 (0.60 kg) and T3 (2.19 kg) followed by T2 (1.93 kg) respectively. Yield of fruit (per ha) of broccoli and tomato in treatment T1 (29.27 t/ha) followed by T4 (17.33 t/ha) and T3 (63.46 t/ha) followed by T2 (56.03 t/ha) respectively. Ultimately, farmers are most concerned with fruit mass produced as this determines food production and/or cash income. It was found that fruit mass was significantly different for treatments T2 and T3 whereas insignificant for T1 and T4 ($p \leq 0.05$).

Higher yields of tomato (67.3 t/ha) were reported for drip micro-tubes (Manjunatha et al., 2001).

Table 4 Mean vegetative growth parameters under different irrigation treatments

Treatments	No. of leaves	LAI	Plant height /cm	Girth /cm	Branches/ secondary head, no.	No. of fruit	Root Length /cm	Yield per plant/ kg	Wet (residue)			Dry (residue)		Dry matter content	
									Crop /kg	AG bio /kg	Root /kg	Crop /kg	Root /kg	Crop residue/%	Root residue/%
T1	140.60	2.46	26.80	11.31	9.20	10.20	29.00	1.01	2.64	3.65	0.089	0.292	0.035	10.97	38.93
T2	30.40	1.60	54.80	3.02	14.20	26.40	30.60	1.93	0.24	2.17	0.018	0.030	0.006	12.53	32.59
T3	53.60	2.08	64.40	4.59	15.40	27.80	32.20	2.19	0.68	2.87	0.033	0.102	0.012	14.71	36.65
T4	57.80	1.48	21.30	6.94	5.80	6.80	22.10	0.60	0.90	1.50	0.045	0.095	0.017	10.20	37.15

3.6 Water Use Efficiency (WUE)

The seasonal water requirements were found to be 20.08, 19.68, 18.61 and 21.06 cm, respectively for treatments T1, T2, T3 and T4 and corresponding WUE were 1.46, 2.85, 3.41 and 0.82 t/ha-cm. The overall efficiency of water use in this experiment was found to be high due to saving of water. Only a small portion of the area was irrigated by a controlled amount of water and deep percolation as well as the evaporation losses was minimum. The seasonal water requirement and WUE of tomato reported by Agrawal et al. (2005) was 27.74 cm and 0.68 t/ha-cm for drip treatments. Singh et al. (2001) reported WUE range from 18.7-6.52 kg/ha-mm for sprouting broccoli. The WUE along with yield and seasonal water requirement for each treatment combination are presented in Table 5.

Table 5 Seasonal water requirement, water use efficiency of tomato and broccoli under different irrigation treatments

Treatments	Average yield/ t • ha^{-1}		Seasonal water requirement/cm		Water use efficiency / t • ha^{-1}-cm	
	Tomato	Broccoli	Tomato	Broccoli	Tomato	Broccoli
T1		29.27	19.68	20.08		1.46
T2	56.03		18.61		2.85	
T3	63.46				3.41	
T4		17.33		21.06		0.82

3.7 Economics

Drip irrigation is suitable for vegetables and orchards but it gives maximum return for vegetables within a season. Table 6 presents the economic analysis of different irrigation treatments.

Table 6 Benefit to cost ratios of tomato and broccoli under different irrigation treatments

S. No.	Costeconomics	LPLC drip irrigation system							
		Broccoli				Tomato			
		Medi-emitters (T1)		Microtubes (T4)		Medi-emitters (T2)		Microtubes (T3)	
		Without subsidy	With 70% subsidy	Without subsidy	With 70% subsidy	Without subsidy	With 70% subsidy	Without subsidy	With 70% subsidy
1	Fixed cost	146,216.77	43,865.03	40,216.77	12,065.03	146,216.77	43,865.03	40,216.77	12,065.03
a	Depreciation	13,159.51	3,947.85	3,619.51	1,085.85	13,159.51	3,947.85	3,619.51	1,085.85
b	Interest	7,310.84	2,193.25	2,010.84	603.25	7,310.84	2,193.25	2,010.84	603.25
c	Repair and maintenance	1462.17	438.65	402.17	120.65	1,462.17	438.65	402.17	120.65
d	Total (a+b+c)	168,149.29	50,444.79	46,249.29	13,874.79	168,149.29	50,444.79	46,249.29	13,874.79
2	Cost of cultivation	51,783.82	51,783.82	51,783.82	51,783.82	54,342.64	54,342.64	54,342.64	54,342.64
3	Seasonal total cost (1d+2), Rs	219,933.11	102,228.61	98,033.11	65,658.61	222,491.93	104,787.43	100,591.93	68,217.43
4	Yield of produce/t • ha^{-1}	29.27	29.27	17.33	17.33	56.03	56.03	63.46	63.46
5	Selling price, Rs/kg	20.00	20.00	20.00	20.00	10.00	10.00	10.00	10.00
6	Income from produce (4×5)	585,379.84	585,379.84	346,591.23	346,591.23	560,341.81	560,341.81	634,600.00	634,600.00
7	Net seasonal income, (6-3), Rs	365,446.73	483,151.23	248,558.13	280,932.63	337,849.89	455,554.39	534,008.07	566,382.57
8	Seasonal BC ratio, (7/3)	1.66	4.73	2.54	4.28	1.52	4.35	5.31	8.30

The Rajasthan State Government has approved the rate per hectare for drip irrigation from Rs 19, 205.71 to Rs 163,400.00 depending upon the crop. The subsidy provided to this micro-irrigation is 70% (DOA, 2009).

It can be seen from the Table that the payback period for all treatments is one season and benefit to cost (B/C) ratio ranges from 1.59 to 5.31 without subsidy and 4.28 to 8.30 with subsidy, hence this could be a viable option for small landholders. Manjunatha et al. (2001) reported B/C, 9.81 for drip micro-tubes in case of high yield tomato.

4 Conclusions

The developed LPLC drip system has satisfactory hydraulic performance. Micro-tubes performed better than medi-emitters. As the payback period for all treatments is a single season and benefit to cost (B/C) ratio in the range of 1.59 to 5.31 without subsidy and 4.28 to 8.30 with subsidy, it can be presented an attractive prospect. Water efficient irrigation methods (LPLC) drip irrigation system that are affordable, divisible and appropriate can significantly improve food production and the livelihoods in water scarce areas of developing countries, promoting greater economic and food security.

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