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Development and Evaluation of a Low Cost Sprinkler Irrigation System for High Value Crops

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ABSTRACT. Modifications were made to improve the design of a low cost, portable, rotating head sprinkler system made of Poly Vinyl Chloride pipes. The system was installed in the field to find the maximum possible number of sprinkler heads which can be operated by a 5 cm delivery outlet centrifugal pump which develops a 16.5 m pressure head. Catch can tests were conducted to evaluate the application rates and the uniformity of wetting with different combinations of sprinklers and lateral spacings.

Maximum pressures developed in the system with 6, 5 and 4 or less than 4 sprinklers were 117.2, 158.6 and 206.8 kPa respectively. Based on these results, single sprinkler tests were carried out using the above three operating pressures. The catch can data were analyzed for different sprinkler and lateral spacings using the CATCH3D computer program.

The 206.8 kPa nozzle pressure showed a cone shaped precipitation profile around the sprinkler. The precipitation profile at 117.2 kPa nozzle pressure showed a doughnut pattern. Slight improvement of the precipitation profile was observed at 158.6 kPa nozzle pressure.

Analysis of results using CATCH3D indicated that the distribution pattern and the application efficiencies at 117.2 kPa nozzle pressure were inappropriate for shallow rooted crops. However, closer spacings (12x12 m) at 117.2 kPa nozzle pressure is appropriate for crops with average rooting depths.

Spacings of 12x18 m or 18x12 m are appropriate for shallow rooted crops at 158.6 kPa or at 206.8 kPa nozzle pressure. These spacings can be increased up to 15x18 m or 18x15 m for crops with average rooting depths.

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INTRODUCTION

Rehabilitation of major irrigation works and major river diversions to augment water supply to these irrigation works have received highest investment priorities in Sri Lanka for the development of dry zone agriculture. Where such schemes cannot provide irrigation water, construction of Agro-wells to cultivate high value crops is receiving a major emphasis at present. However, low productivity of traditional gravity irrigation in the former case and the limited water supply in the latter case has made it necessary to develop and adopt alternative water application methods to utilize irrigation water effectively and productively.

Sprinkler irrigation is one such alternative water application method. However, the high overhead cost of available commercial systems is beyond the economic reach of a majority of small holder farmers. This has been a major limitation to the application of sprinkler irrigation technology on a wider scale. Therefore, availability of a low cost sprinkler system which can operate off commonly available low pressure water pumps can significantly contribute to the effective utilization of scarce irrigation water. Also, it could meet the needs of the majority of the farming community who cannot afford the commercially available systems at present.

The main objectives of the study presented in this paper were to develop a low cost sprinkler irrigation system, evaluate the system under local field conditions, and analyze the performance of the sprinkler system through computation of the water application efficiencies under various lateral and sprinkler spacings.

MATERIALS AND METHODS

The study was conducted in two stages, namely, system development and system evaluation. Following the preliminary tests, a complete sprinkler system was developed using PVC pipes at the workshop of the Department of Agricultural Engineering.

The mainline, lateral lines, and sprinklers were coupled using a quick coupling system made of PVC to make the system portable. The rotating sprinkler head was made of PVC components and the rotation of the sprinkler was obtained by the vibration of a PVC flap due to the impact of water jet ejected through the nozzle. The complete system was installed at the Meewathura farm of the University of Peradeniya. The lateral line, consisting of 15 lateral sections, was installed in the down hill direction. Six riser turnouts were installed along the lateral line at every 12 m. These riser turnouts were connected to the sprinkler heads via sprinkler risers and quick couplers. The system was operated off a commonly available low pressure (16.5 m pressure head) centrifugal pump with a 5 cm diameter delivery outlet. Preliminary tests were conducted to find the maximum possible number of sprinklers that can be operated off the pump without significantly reducing the effective diameter of sprinkling.

The irrigation application performance of the system was evaluated using the standard catch can test. An isolated sprinkler was set up at the centre of a hundred catch cans which were arranged at 3 m spacing on a square grid. Single sprinkler tests were conducted for three different nozzle pressures of 117.2, 158.6 and 206.8 kPa. The pressures were adjusted by controlling the rpm of the pump, because the maximum pressure indicated 117.2 kPa for 6, 158.6 kPa for 5 and 206.8 kPa for 4 or less than 4 sprinklers. The pressure and flow rate were adjusted before starting the tests. After attaining the steady state, pressures at the nozzles were recorded with a pitot tube which was connected to a pressure gauge. Also sprinkler discharge was measured by collecting the water into a large container and recording the time and volume collected. The tests were allowed to run for about two hours. Collected water in each of the catch cans was measured to the nearest ml with a measuring cylinder.

Twenty four hours following sprinkler application, soil samples were collected from all the catch can points using a soil auger up to a depth of 30 cm. These samples were collected into polyethylene bags which were then sealed to prevent moisture loss. All the samples were analyzed in the laboratory to determine the moisture content by gravimetric method.

The relationship between pressure head and discharge from a sprinkler can be expressed by the orifice equation:

$$q = K_d \sqrt{P} \qquad (1)$$

where:

q = sprinkler discharge, l/min (or gpm)
K_d = appropriate discharge coefficient for the sprinkler and nozzle combined and the specific units used.

P = sprinkler operating pressure kPa (or psi)

The discharge of each nozzle at different pressures was measured to compute the sprinkler discharge coefficients. Each measurement was repeated at least thrice to minimize errors. Nozzle diameter and cross sectional area were recorded. The value K_d was computed by using linear regression techniques.

Nozzle discharge for different sizes of nozzle at different pressures can be predicted by;

$$q = K_o A \sqrt{P} \qquad (2)$$

If the value q of equation 1 is substituted to eq 2 then;

$$K_o = K_d / A \qquad (3)$$

Hence the nozzle discharge for different sizes of nozzle can be predicted by the orifice equation.

$$q = K_d / A_5 * A * \sqrt{p} \qquad (4)$$

In order to measure the system discharge of the sprinkler system with five sprinkler heads, the suction line of the water pump of this system was connected to a large galvanized iron tank with a known cross sectional area. This tank was filled with water to a known height and the water pump was turned on to attain the maximum discharge of the system. This discharge was allowed to continue for few minutes until the entire system reached a steady state. The initial height of the water in the tank was maintained by adding water to the tank while the pump was operating.

Once the steady state was reached, addition of water to the tank was stopped. The initial water level and the water level after 60 seconds were recorded. Using the discharged water volume within a known time duration, discharge rate and drainage losses were computed. The procedure was repeated thrice in order to minimize errors.

RESULTS AND DISCUSSION

The cost of the sprinkler system which includes materials, manufacturing costs and a profit margin is about Rs. 50,000/- per ha without the pump. Thus, for average land holding size of 0.5 ha the system cost is Rs. 25,000/- which is about 1/6th of the cost of commercially available systems. The system is completely portable and easily assembled which is one of the main advantages. The diameter of coverage per sprinkler ranged between 20 - 25 m. Six sprinklers could be operated at a time without reducing the effective diameter of coverage when operated off a pump of 5 cm delivery outlet which can develop a pressure head of 16.5 m.

Three dimensional plots of precipitation profiles at different nozzle pressures were obtained using the CATCH3D computer program. As shown by Figures 1 and 2, the distribution pattern of the precipitation profile was a doughnut pattern at 117.2 kPa nozzle pressure and a slight improvement of the distribution profile was observed at 158.6 kPa. Conical shape of precipitation profile occurred around the sprinkler at 206.8 kPa nozzle pressure (Figure 3). Therefore, 206.8 kPa nozzle pressure was the most satisfactory pressure for this system.

Efficiency parameters calculated by CATCH3D (Allen, 1988) are listed in Table 1. Uniformity coefficient (CU) was calculated by four different types of formulae for normal application.

Test results shown in Table 1 indicate that the average uniformity coefficient increased with the nozzle pressure. From Table 1, it is clear that all sprinkler and lateral spacings for 117.2 kPa nozzle pressure were inappropriate for shallow rooted crops. This is because, CU and DU values are less than 85% and 78% respectively for normal application. Spacing of 12x12 m R, 15x12 m R, and 12x12 m T (where R represents rectangular and T represents triangular spacing) indicates that CU values are greater than 78% but less than 85% and DU values are greater than 65% but less than 76%. Therefore, these three spacings at 117.2 kPa nozzle pressure can be used for crops of average root zone depths. It is clear from Table 1 that CU values for alternate irrigation are higher than 78% for all spacings.

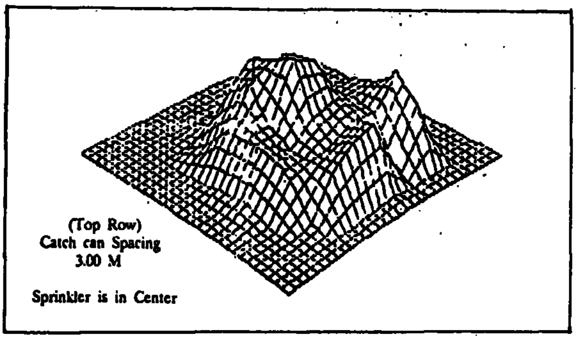


Figure 1. Precipitation Profile of Single Sprinkler Test for 5 mm Nozzle at 17 psi Nozzle Pressure.

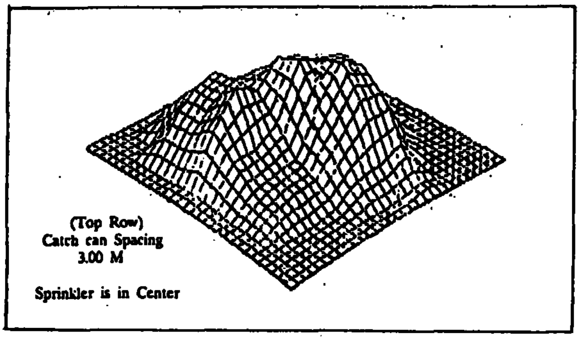


Figure 2. Precipitation Profile of Single Sprinkler Test for 5 mm Nozzle at 23 psi Nozzle Pressure.

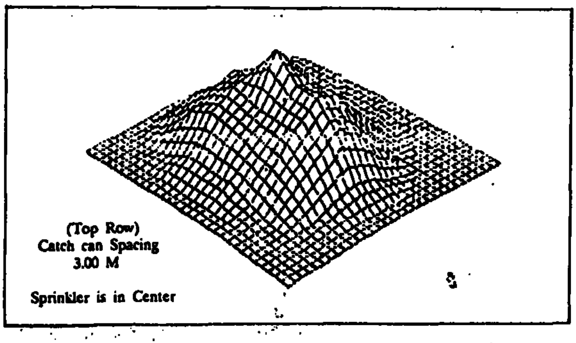


Figure 3. Precipitation Profile of Single Sprinkler Test for 5 mm Nozzle at 30 psi Nozzle Pressure.

Table 1. Performance parameters evaluated using CATCH3D programme (single sprinkler test).

Nozzle pres.	Spacing Meters Se x Sl	DU	Uniformity Coefficients (CU)					AELQ %	AELH %
			Chr	LH	DU	SD	CUalt		
117.2 kPa	12x12 R	73.3	78.8	80.1	83.2	76.8	88.8	46.0	50.2
	15x15 R	60.2	70.5	69.3	75.0	71.6	84.0	37.8	43.4
	15x12 R	62.8	78.5	78.6	76.6	76.4	88.6	39.4	49.3
	18x12 R	57.4	74.1	74.4	73.2	74.4	86.1	36.0	46.7
	18x15 R	52.8	69.8	69.8	70.3	68.9	83.6	33.1	43.8
	15x18 R	57.7	67.5	69.2	73.4	66.0	82.2	36.2	43.4
	12x18 R	61.0	67.0	69.1	75.4	69.4	81.9	38.2	43.3
	12x12 T	72.2	80.7	80.7	82.5	81.7	89.8	45.3	50.6
	15x15 T	60.0	70.7	70.7	74.8	72.2	84.1	37.7	44.4
	15x12 T	67.3	76.7	77.1	79.4	77.0	87.6	42.2	48.4
	18x12 T	65.8	75.4	76.0	78.4	74.9	86.8	41.3	65.8
	18x15 T	59.9	72.7	72.9	74.7	71.6	85.2	37.6	45.7
	15x18 T	58.4	66.5	68.7	73.8	67.8	81.6	36.7	43.1
	12x18 T	60.5	65.8	67.8	75.1	69.1	81.1	38.0	42.6
158.6 kPa	12x12 R	78.0	84.0	84.0	86.1	85.1	91.7	57.3	61.7
	15x15 R	72.3	81.9	81.1	82.5	82.0	90.5	53.1	59.6
	15x12 R	75.7	83.4	83.6	84.7	83.8	91.3	55.6	61.4
	18x12 R	67.6	77.8	77.8	79.6	79.3	88.2	49.6	57.1
	18x15 R	63.8	75.7	76.3	77.2	75.2	87.0	46.9	56.0
	15x18 R	71.6	81.0	81.1	82.1	81.8	90.0	52.6	59.6
	12x18 R	81.1	87.7	87.8	88.1	87.9	93.7	59.6	64.5
	12x12 T	77.9	85.0	85.3	86.0	85.7	92.2	57.2	62.6
	15x15 T	68.2	77.6	78.0	80.0	78.4	88.1	50.0	57.2
	15x12 T	69.1	77.3	77.7	80.5	79.0	87.9	50.7	57.0
	18x12 T	58.5	68.8	68.9	73.8	71.1	82.9	42.9	50.6
	18x15 T	55.0	70.1	70.5	71.6	71.1	83.7	40.4	51.8
	15X18 T	67.8	80.6	80.7	79.7	80.8	89.8	49.8	59.2
	12x18 T	78.7	87.2	87.3	86.6	86.9	93.4	57.8	64.1
206.8 kPa	12x12 R	82.2	87.7	87.7	88.8	88.5	93.7	47.5	50.7
	15x15 R	73.5	79.1	78.4	83.3	80.5	88.9	42.5	45.3
	15x12 R	86.5	92.4	92.4	91.5	91.1	96.1	50.0	53.4
	18x12 R	83.1	87.9	88.1	89.4	88.3	93.8	48.1	50.9
	18x15 R	68.1	79.8	80.0	79.9	78.8	89.3	39.4	46.2
	15x18 R	46.7	62.3	62.6	66.4	64.5	78.9	27.0	36.2
	12x18 R	43.6	62.4	62.6	64.5	64.2	79.0	25.2	36.2
	12x12 T	82.2	89.8	89.9	88.8	89.7	94.8	47.5	51.9
	15x15 T	70.6	79.3	79.3	81.4	80.4	89.1	40.8	45.8
	15X12 T	81.7	88.8	89.1	88.4	88.8	94.3	47.2	51.4
	18x12 T	84.8	89.8	90.0	90.4	89.2	94.8	49.0	52.0
	18x15 T	71.6	80.5	80.7	82.1	80.6	89.7	41.4	46.6
	15x18 T	44.9	62.2	62.6	65.3	65.1	78.9	25.9	36.1
	12x18 T	43.6	62.4	62.6	64.5	64.5	79.0	25.2	36.2

At 158.6 kPa nozzle pressure, the CU value is greater than 85% for 12x12 m R which was computed from distribution uniformity and standard deviation. The value of CU is nearly 85% for spacing 12x12 m R from Christiansen and low half. Also the CU value is greater than 85% for spacing of 12x18 m R, 12x12 m T and 12x18 m T obtained from all four types of formulae. These four spacings also indicate DU values greater than 76%. Therefore, these four spacings are applicable to shallow rooted crops at nozzle pressure of 158.6 kPa. A CU value higher than 78% and less than 85% is observed for 15x15 m R, 15x12 m R, 18x12 m R, 15x18 m R and 15x18 m T at the nozzle pressure of 158.6 kPa. These five spacings show DU values greater than 65% but less than 76%. Therefore, these five spacings can be recommended for deeper rooted crops, but not for shallow rooted crops.

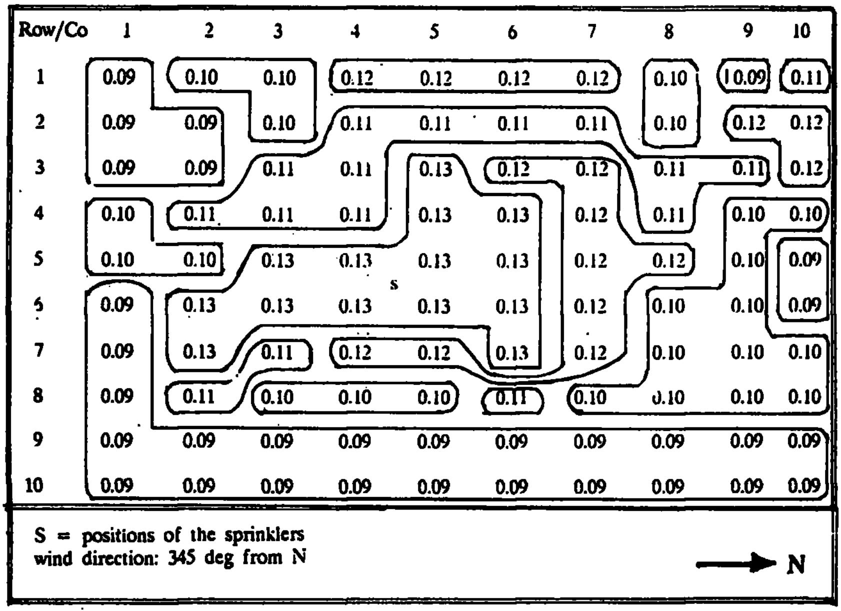
Spacings of 12x12 m R, 15x12 m R, 18x12 m R, 12x12 m T, 15x12 m T and 18x12 m T at 206.8 kPa nozzle pressure indicate CU and DU values greater than 85% and 75% respectively. Hence these spacings are suitable for crops with high economic value. CU and DU values are greater than 78% and 65% respectively for the spacings of 15x15 m R, 18x15 m R, 15x15 m T and 18x15 m T at 206.8 kPa. It is also clear from Table 1 that these four spacings indicate CU and DU values less than 85% and 76% respectively. These four spacings can be recommended for economical crops at 206.8 kPa nozzle pressure.

As shown by Table 1, application efficiencies of low quarter (AELQ) and low half (AELH) decreased with the increase in spacing but, 18x12 m T at 117.2 kPa, 12x18 m R and 12x18 m T at 158.6 kPa and 18x12 m R and 18x12 m T at 206.8 kPa nozzle pressures provide higher efficiency than at lower spacings.

As shown by Figure 4, slight variation of moisture distribution pattern was observed in the field, 24 hours after irrigation, with a single sprinkler head. Figure 5 shows that the irrigation with single lateral line improves the moisture distribution pattern in the field.

The sprinkler discharge coefficients, K_d and K_o were 0.0289 and 0.0015 respectively. Hence the nozzle discharge for different size of nozzle can be predicted by the orifice equation.

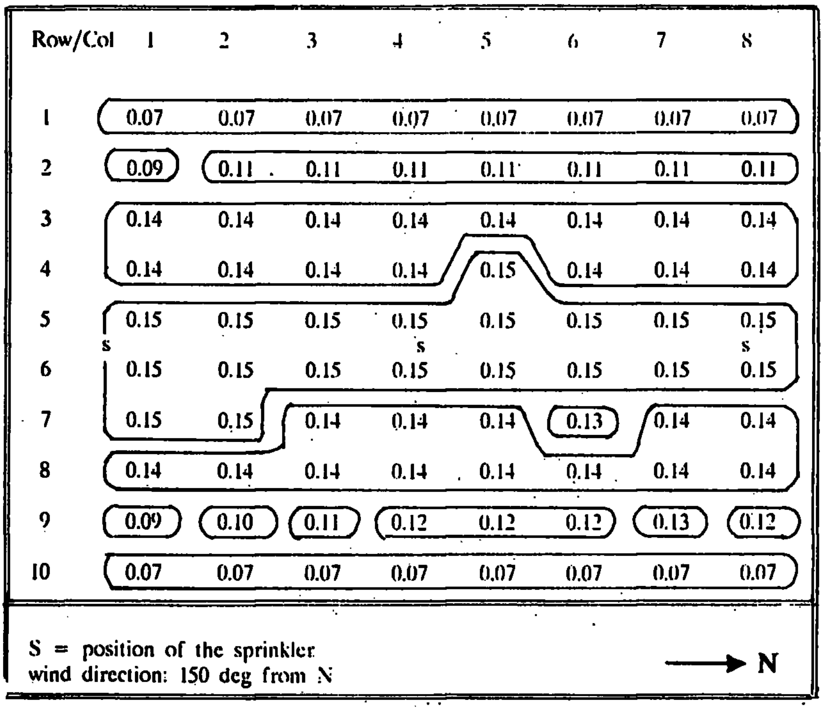
$$q = 0.0015A\sqrt{p} \qquad (5)$$



Row/Co	1	2	3	4	5	6	7	8	9	10
1	0.09	0.10	0.10	0.12	0.12	0.12	0.12	0.10	0.09	0.11
2	0.09	0.09	0.10	0.11	0.11	0.11	0.11	0.10	0.12	0.12
3	0.09	0.09	0.11	0.11	0.13	0.12	0.12	0.11	0.11	0.12
4	0.10	0.11	0.11	0.11	0.13	0.13	0.12	0.11	0.10	0.10
5	0.10	0.10	0.13	0.13	0.13	0.13	0.12	0.12	0.10	0.09
6	0.09	0.13	0.13	0.13	0.13	0.13	0.12	0.10	0.10	0.09
7	0.09	0.13	0.11	0.12	0.12	0.13	0.12	0.10	0.10	0.10
8	0.09	0.11	0.10	0.10	0.10	0.11	0.10	0.10	0.10	0.10
9	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09
10	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09

S = positions of the sprinklers
wind direction: 345 deg from N

Figure 4. Distribution Pattern of the Mass Water Content at 24 Hours after Irrigation of the Field.



Row/Col	1	2	3	4	5	6	7	8
1	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07
2	0.09	0.11	0.11	0.11	0.11	0.11	0.11	0.11
3	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14
4	0.14	0.14	0.14	0.14	0.15	0.14	0.14	0.14
5	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
	s			s				s
6	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
7	0.15	0.15	0.14	0.14	0.14	0.13	0.14	0.14
8	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14
9	0.09	0.10	0.11	0.12	0.12	0.12	0.13	0.12
10	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07

S = position of the sprinkler
wind direction: 150 deg from N

Figure 5. Distribution Pattern of the Mass Water Content of soil at 24 Hours after Single Lateral Irrigation.

Estimated leaks and Drainage Losses were 8.33% for this system with five sprinkler heads.

CONCLUSIONS

The following conclusions can be drawn from the results of the sprinkler evaluation study.

1. Results showed that the distribution pattern of moisture in the field at 24 hours after irrigation with a single lateral line was reasonably uniform.

2. The distribution pattern at 117.2 kPa nozzle pressure is inappropriate to the shallow rooted crops. But 12x12 m R, 15x12 m R and 12x12 m T spacings at 17 psi nozzle pressure can be used for crops with average rooting depths.

3. The spacings of 12x18 m R and 12x18 m T are appropriate for shallow rooted crops at 158.6 kPa nozzle pressure. These spacings can be increased up to 15x18 m R or 15x18 m T for deeper rooted crops to minimize the system cost.

4. The spacings of 18x12 m R or 18x12 m T are suitable for shallow rooted crops at 206.8 kPa nozzle pressure. To minimize the system cost this spacings can be increased up to 18x15 m R or 18x15 m T for crops with average rooting depths.

5. The sprinkler system made out of PVC can be used successfully to irrigate the crops and is economically feasible for small holder farmers growing high value crops because of its low cost, portable nature and the ease of assembly.

6. Leaks and drainage losses were less than 10%. Therefore, this system can be recommended for agricultural purposes.

REFERENCES

Allen, R.G. (1988). CATCH3D Manual, Dept. Ag. and Irrig. Eng. Irrig. Software Eng. Div. UMC 4105, Utah State University, Logan, UT.