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Evaluation of Micro-Sprinkler Characteristics Under Various Operating Conditions

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Abstract

The performance characteristics of micro-sprinkler have been evaluated under various operating conditions in respect of pressure discharge relationship, precipitation pattern and field performance in terms of uniformity coefficient, emission uniformity, and distribution uniformity. Suitable operating pressure and spacing between micro-sprinklers have been tested at operating pressure ranging from 0.75 to 2.0 kg/cm^2 for pressure-discharge relationship and uniformity coefficient, emission uniformity and distribution uniformity. The experiment were conducted the pressure ranges from (1.0 to 2.5 kg/cm^2) for precipitation pattern treatment and micro-sprinkler spacing of 1.5 × 1.5 m, 2.25 × 2.25 m, 3.0 × 3.0 m and 3.75 × 3.75 m under low wind speed condition. Pressure discharge relationship has been developed in the form of power type equation $Q = 44.45\ P^{0.78}$. Precipitation pattern was found to be flat elliptical type at low operating pressure and it gradually changed to triangular type with increase in pressure. The emission uniformity was found to be more than 90%. The uniformity coefficient and distribution uniformity increased with increasing operating pressure and decreased with increase in micro-sprinkler spacing. It was conducted based on operating condition that the micro-sprinkler should be operated at a pressure range of 1.5 to 2.0 kg/cm^2 and at spacing of 1.5 × 1.5 m.
Key words : Micro-sprinkler, Precipitation pattern, Pressure-discharge relationship.

Water is the elixir of life. It is a vital element which significantly affects all aspect of life. Water is invaluable natural resources, a basic human need and country's treasure. It is const as a soul for "life sustaining profession" and economic development of any country. It is therefore prudent for researchers and scientists to think on conservation and efficient utilization of water to maximize production per unit volume of the limited available water resources. Micro-sprinkler irrigation method is the intermediate irrigation system between sprinkler irrigation and drip irrigation system. It applies water in the form of spray and that operate at low pressure on the low flow rates and maximize the potential area to be irrigated from limited water resources. The ideal micro-irrigation system assumes the delivery of equal volume of water from all micro-sprinkler, the application uniformity affected by variation in pressure in the distribution system. The flow from micro-sprinkler at different operating pressures may be determined by pressure discharge relationship (1—4). Water distribution uniformity from micro-irrigation is necessary to maximize the crop yield and to improve the quality of produce. In shallow rooted crops, a high uniformity of application is desirable while in deep rooted crops a lower uniformity of application may be acceptable. The uniform water distribution is also necessary for efficient use of available irrigation water. For this reason the emission uniformity, uniformity coefficient and distribution uniformity may be taken as design variables for micro-irrigation system. An attempt was made in the present study to obtain the basic information on these aspects for evaluation of micro-sprinkler characteristics under various operating conditions.

Methods

The experiment was conducted at instructional

Table 1. Precipitation characteristics as influenced by operating pressure given by Keller method.

	Precipitation characteristics	Operating pressure (kg/cm^2) 1.0	1.5	2.0	2.5
1	Effective radius (m)	1.0	1.25	1.5	1.75
2	Average precipitation depth, mm/h	7.69	7.73	8.46	9.23
3	Effective maximum depth, mm/h	15.56	14.14	14.00	14.95
4	Absolute maximum depth, mm/h	19.80	17.54	17.26	21.78
5	Mean application depth, mm/h	11.40	8.08	6.72	7.62
6	Distribution characteristics (%)	24.07	17.20	18.70	36.27
7	Coefficient of variation	0.67	0.77	0.86	0.83

farm of College of Technology and Engineering, Udaipur. The experimental set up consisted of open well as water source, Submersible pump (5 HP), hydro cyclone filter, sand filter, screen filter, pressure gauge, mainline (PVC, dia 75 mm), sub-main line (PVC, dia 63 mm), control valve to regulate the flow, lateral line (LDPE, dia 16 mm) micro-sprinklers.

Pressure Discharge Relationship

Following pressure discharge relationship for micro-sprinkler as proposed by Keller and Karmeli (6) was used.

$$Q - K P^X$$

Where Q = discharge of micro-sprinkler, 1ph, P = operating pressure, kg/cm^2, K = characteristics constant, x = discharge exponent.

Precipitation Pattern

The catch can was placed at the grid of 0.5 × 0.5 m formed around the micro-sprinklers to determine the precipitation pattern. The precipitation pattern was studied by drawing contours of equal precipitation depth and distribution profile.

Effective Radius (Re)

Effective radius is the distance between center of micro-sprinkler and the point at which the profile cut the horizontal axis on precipitation pattern (7).

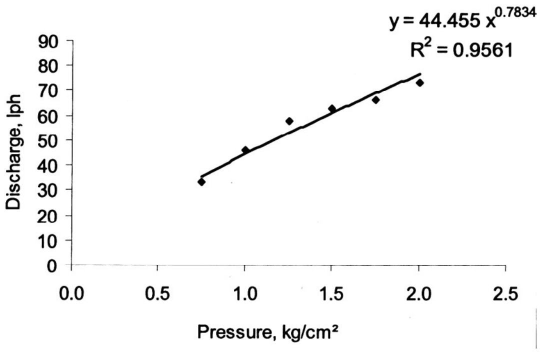

Figure 1. Pressure discharge relationship for micro-sprinkler.

Average Application Depth (mm/h)

Keller and Merriam (7) used concentric ring approach to calculate average precipitation depth.

$$\text{Average precipitation pattern} = \frac{d_1 + d_2 + d_3 + d_4}{4}$$

Where, d_1, d_2, d_3 and d_4 are average depths in 1st, 2nd, 3rd, and 4th concentric rings, respectively around the micro-sprinklers.

Effective Maximum Depth (mm/h)

Effective maximum depth is calculated as the average value in 5% of total cans having maximum collection and is expressed as mm/h.

Absolute Maximum Depth (mm/h)

Absolute maximum depth is the maximum of all readings, from the observed data.

Mean Application Depth (mm/h)

Mean application depth is calculated as the average depth between the area constrained by effective radius.

Distribution Characteristics (DC)

This term characterizes the water distribution of

Table 2. Estimated value of uniformity coefficient, emission uniformity and distribution for different operating pressure and micro-sprinkler spacing.

Operating pressure (kg/cm)	Spacing (m)	Average of UC, EU, DU (%) Uniformity coefficient	Emission uniformity	Distribution uniformity
0.75	1.5 × 1.5	80.52	96.13	71.94
	2.25 × 2.25	70.16	95.73	68.06
	3.0 × 3.0	66.74	95.25	54.40
	3.75 × 3.75	34.54	94.96	22.32
1.00	1.5 × 1.5	81.96	96.36	73.47
	2.25 × 2.25	72.94	96.24	68.15
	3.0 × 3.0	70.28	95.38	63.23
	3.75 × 3.75	42.47	95.16	32.59
1.25	1.5 × 1.5	82.99	96.61	73.50
	2.25 × 2.25	77.64	96.46	70.05
	3.0 × 3.0	74.69	95.45	64.29
	3.75 × 3.75	46.52	95.38	36.60
1.50	1.5 × 1.5	84.46	97.48	73.52
	2.25 × 2.25	81.50	96.80	70.26
	3.0 × 3.0	76.78	95.96	66.45
	3.75 × 3.75	51.36	95.51	39.52
1.75	1.5 × 1.5	85.53	97.75	74.35
	2.25 × 2.25	81.93	97.22	71.02
	3.0 × 3.0	77.64	96.13	68.52
	3.75 × 3.75	58.18	95.84	47.16
2.00	1.5 × 1.5	85.77	98.94	74.84
	2.25 × 2.25	83.98	97.82	73.62
	3.0 × 3.0	78.72	96.91	69.84
	3.75 × 3.75	62.68	96.47	48.69

single sprinkling device. It was calculated by using the following relationship

$$\text{Distribution Characteristic} = \frac{\text{Area receiving the depth greater than average depth}}{\text{Total wetted area}} \times 100$$

Coefficient of Variation (CV)

Coefficient of variation was calculated as given by Keller and Merriam (7)

$$CV = \frac{\sigma}{da}$$

Where, da = mean application depth

$$\sigma = \sqrt{\frac{\sum X^2}{N}}$$

Where, $\sum X^2$ = Deviation from mean depth, mm, N = Number of observations.

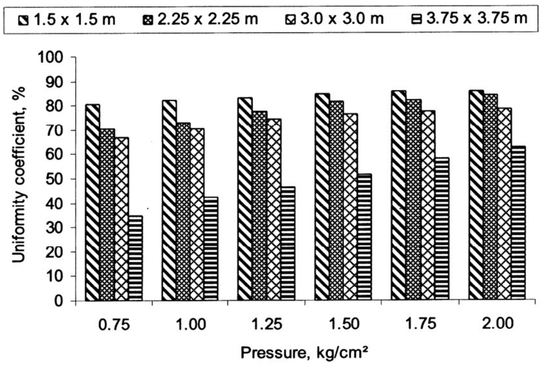

Figure 2. Uniformity coefficients as influenced by operating pressure for different spacing of micro-sprinkler.

Uniformity Coefficient (UC)

The uniformity coefficient (UC) was determined for the operating pressure heads of 0.75, 1.0, 1.25, 1.50, 1.75 and 2.0 kg/cm^2 for 1.5 × 1.5 m, 2.25 × 2.25 m, 3.0 × 3.0 m, and 3.75 × 3.75 m micro-sprinkler spacing. Uniformity coefficient (UC) was determined by Christiansen's formula (8) as follows

$$CU = 1 - \frac{\sum X}{mn} \times 100$$

Where, CU = Uniformity Coefficient (per cent), m = Average value of all observations (mm), n = Total number of observation points, X = Numerical deviation of individual observations from the average application rate (mm).

Emission Uniformity (EU)

This term has generally been used to describe the emitter flow variation for a micro-sprinkler irrigation unit. The following equation was used for determining the emission uniformity as suggested by Keller and Karmeli (6)

$$EU = 100 \times \frac{q_n}{q_a}$$

Where, EU = emission uniformity, per cent, q_n = aver-

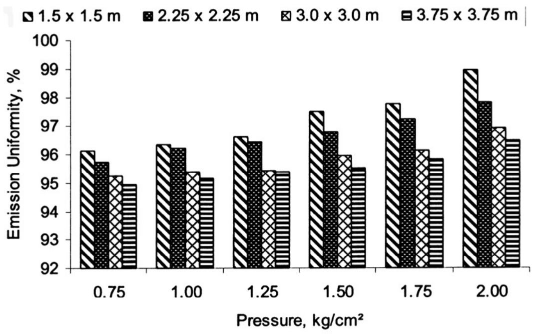

Figure 3. Emission uniformity as influenced by operating pressure for different spacing of micro-sprinkler.

age of the lowest $^1/_4$ of the emission point discharges for field data, 1ph, q_a = average emission point discharges of test sample operated at the reference pressure head, 1ph.

Distribution Uniformity (DU)

Distribution uniformity indicates the degree to which the water is applied uniformity over the area and was determine by using the following relationship

$$DU = \frac{\text{Average low quarter depth of water caught}}{\text{Average depth of water caught}} \times 100$$

Where, DU = Distribution uniformity of micro-sprinkler, per cent

Results and Discussion

The data regarding the operating pressure, discharge were collected to develop pressure-discharge relationship. Precipitation pattern was studied by uniformity coefficient, emission uniformity and distribution uniformity for evaluation micro-sprinkler characteristic.

Pressure Discharge Relationship

The discharge of micro-sprinkler was under study was influenced with the operating pressure. Maximum discharge of 73.10 1ph was recorded corresponding to the operating pressure of 2.0 kg/cm^2 and minimum of 32.99 1ph for 0.75 kg/cm^2 operating pressure. Mathematical equation of the form $Q = KP^x$ was developed for the micro-sprinkler under study. The characteristic constant (K) was found 44.45 and discharge exponent (x) as 0.78 with correlation coefficient 0.95. The high value of correlation coefficient (R^2) indicated the goodness of fit. An attempt was also made to establish the pressure discharge relationship as influenced by the different spacing treatments under study. Functional relationship between the operating pressures and discharge was estimated with the help of power type mathematical equation of form $Q = K P^x$ for each spacing. The characteristic constants (K) discharge exponents (x) and correlation coefficients (R^2) were found to be in the range of 43.99 to 44.91, 0.77 to 0.79 and 0.95 to 0.96 respectively. Thus it can be concluded that spacing did not influenced significantly characteristic constants, discharge exponent and correlation coefficient respectively.

Precipitation Pattern

Precipitation pattern in terms of effective radius, average application depth, effective maximum depth, absolute maximum depth, mean depth, distribution characteristics and coefficient of variation estimated by Keller method for 1.0, 1.5, 2.0 and 2.5 kg/cm^2 operating pressure.

From the precipitation contours at an interval of 1.5 mm it was observed that contours were closely spaced nearer to the micro-sprinkler and widely spaced towards the periphery. The distribution profile were also drawn and studied to get study the non uniformity in precipitation distribution. At lower operating pressure (1.0 kg/cm^2) the shape of the distribution profile was of flat elliptical type which gradually changed to triangular type with increase with operating pressure. Flat elliptical type of distribution profile is the desired profile which allow minimum overlapping of adjacent micro-sprinkler from uniform distribution of irrigation water and hence wider spacing between the micro-sprinklers also keep the total cost of system on the lower side compared to the micro-sprinklers having triangular type of distribution necessitating closer spacing between them for

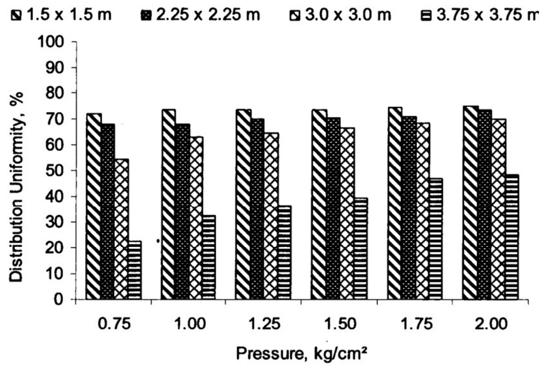

Figure 4. Distribution uniformity as influenced by operating pressure for different spacing of micro-sprinkler.

uniform distribution of pattern, thus involving higher cost per unit area.

Effective Radius

Effective radius was found to be ranging from 1.0 to 1.75 m for 1.0 to 2.5 kg/cm^2 operating pressure respectively. Thus if we consider the overlapping is as 50 per cent, under low wind speed condition the spacing between micro-sprinkler operated at 1.0 kg/cm^2 should be 1.0 m and when the system is operated at 2.5 kg/cm^2 the maximum spacing with 50 per cent overlapping should be 1.75 m. However the system operation at low pressure (1.0 kg/cm^2) causes increase in cost and high pressure (2.5 kg/cm^2) may reduce uniformity of precipitation pattern. Thus if the system i.e. run in between operating pressure of 1.5 to 2.0 kg/cm^2 the maximum spacing can run from 1.25 m to 1.5 m with the 50 per cent overlapping under low wind speed condition (Table 1).

Average Application Depth

Keller and Merriam (7) method was used for estimating average application depth for 1.0, 1.5, 2.0 and 2.5 kg/cm^2 operating pressures for micro-sprinkler under study. For 1.0, 1.5, and 2.0 kg/cm^2 operating pressure the values of average precipitation were recorded 7.69, 7.73, and 8.46 mm/hr respectively (Table 1). The maximum average application depth of 9.23 mm/hr for 2.5 kg/cm^2 operating pressure was recorded.

Effective Maximum Depth

Higher effective maximum depth indicated the concentration of precipitation nearer to the center of the micro-sprinkler. Lower value of effective maximum depth indicated nearly uniform distribution of irrigation water right from the center to the periphery is also confirmed.

Absolute Maximum Depth

Absolute maximum depth of 19.80, 17.54, 17.26 and 21.78 mm/hr were recorded for 1.0, 1.5, 2.0 and 2.5 kg/cm^2 operating pressures respectively (Table 1). A lower value of absolute maximum depth 17.26 mm/hr for 2.0 kg/cm^2 is indicative of superior precipitation distribution pattern over other pressures under study.

Mean Application Depth

Mean application depth of 11.40, 8.08, 6.72 and 7.62 mm/h were recorded for 1.0, 1.5, 2.0 and 2.5 kg/cm^2 operating pressure respectively (Table 1).

Distribution Characteristics

The values estimated were 24.07, 17.20, 18.70 and 36.27% for 1.0, 1.5, 2.0 and 2.5 kg/cm^2 operating pressure respectively (Table 1).

Coefficient of Variation (CV)

The estimated coefficients of variation (CV) were 0.67, 0.77, 0.86 and 0.83 for 1.0, 1.5, 2.0 and 2.5 kg/cm^2 operating pressure respectively (Table 1). Lower values of coefficient of variation indicated the superiority of precipitation pattern corresponding to 1.0 kg/cm^2 operating pressure.

Application Uniformity

Uniformity coefficient, emission uniformity and distribution uniformity was operated at 0.75, 1.0, 1.25, 1.5, 1.75 and 2.0 kg/cm^2 operating pressure for 1.5 × 1.5 m, 2.25 × 2.25 m, 3.0 × 3.0 m and 3.75 × 3.75 m micro-sprinkler spacing.

Uniformity Coefficient

The relationship between operating pressure and uniformity coefficient (UC) for different micro-sprinkler spacing of the form UC = m P^n was developed. The values of constant 'm' and 'n' were found in the range of 33.85 to 80.18 and 0.037 to 0.325 respectively. The values of exponent 'n' indicate the variation of uniformity coefficient with respect to operating pressure. The lower values indicate less variation of uniformity coefficient with operating pressure and vice-versa. The characteristic constant 'm' is highest in the spacing of 1.5 × 1.5 m, indicating at least 80 per cent uniformity coefficient at 1.0 kg/cm^2 pressure which is acceptable for desirable performance of the system. This confirms that the spacing of 1.5 × 1.5 m is suitable for micro-sprinkler as compared to higher spacing.

Emission Uniformity (EU)

The emission uniformities of the system for different operating pressure and micro-sprinkler spacing were calculated by the equation given by Keller and Karmeli (6). It was observed that at 0.75 kg/cm^2 operating pressure the value of emission uniformity gradually decreased from 96.13 to 94.96% when spacing were increased from 1.5 × 1.5 m to 3.75 × 3.75 m. Whereas when operating pressure was changed from 0.75 to 2.0 kg/cm^2 for micro-sprinkler spacing of 1.5 × 1.5 m the emission uniformity values changed from 96.13 to 98.94%. Thus it was observed that emission uniformity did not change substantially either due to operating pressures or due to micro-sprinkler spacing (Table 2).

Distribution Uniformity (DU)

The distribution uniformity of micro-sprinkler system was estimated by Keller and Merriam (7) formula for operating pressures and spacing. For micro-sprinkler spacing of 1.5 × 1.5 m and operating pressure of 0.75 kg/cm^2, the estimated values of distribution uniformity was 71.94%. For the same operating pressure when spacing were increased to 2.25 × 2.25 m, 3.0 × 3.0 m and 3.75 × 3.75 m the values of distribution uniformity were 68.06, 54.40 and 22.32% respectively indicating that for given operating pressure substantial reduction in distribution uniformity micro-sprinkler need to be operated at higher pressure when closely spaced (Table 2).

The linear relationship was observed between operating pressure and distribution uniformity. Straight line equation of the form DU = C P + d was fitted to establish the functional relationship. The values of intercept (d) were found in the range of 71.88 to 19.96 whereas the slope of line (c) was found in the range of 0.49 to 5.09. The correlation coefficient (R^2) was higher than 0.85. Higher value of R^2 indicated the goodness of fit.

Conclusion

Following conclusions are drawn from the present investigation. Pressure-discharge relationship can be very well established by the power type equation of the form Q = K P^x indicated that discharge increases with increase in the operating pressure. However this increase gets stabilized after the pressure exceeds 1.5 kg/cm^2. Precipitation pattern was flat elliptical type at low operating pressure and it gradually changed to triangular type with increase in pressure. The precipitation performance parameter indicated that the micro-sprinkler should be operated at 1.5 to 2.0 kg/cm^2 under low wind speed condition. The relationship between uniformity coefficient and operating pressure for spacing under consideration was found to be power type (UC = m P^n). The results of uniformity coefficient, emission uniformity and distribution uniformity indicated that the micro-sprinkler should be operated at a pressure range of 1.5 to 2.0 kg/cm^2 and suitable spacing for this pressure range was found to be 1.5 × 1.5 m. The saving in number of sprinklers per hectare can be achieved as 55 and 36% with the spacing of 1.5 × 1.5 m and 1.25 × 1.25 m respectively, as compared to 1.0 × 1.0 m spacing. Similarly, the saving of 33 per cent and 20 per cent in lateral length per hectare can be achieved with the same spacing as compared to spacing of 1.0 × 1.0 m. The relationship between distribution uniformity and operating pressure was found to be linear (DU = C P + d).

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