

PERFORMANCE EVALUATION OF MINI-SPRINKLER IRRIGATION SYSTEM UNDER DIFFERENT PRESSURES AND SPACINGS

Abstract

Aims: The present investigation a mini sprinkler system was evaluated for its hydraulic performance. The experiment was conducted to evaluate the hydraulic performance using a mini sprinkler system having “double nozzle - full circle” sprinkler.

Study Design: It was arranged in randomized block design.

Place and Duration of Study: The research experiment was conducted at Instructional Farm of Pravara’s Sindhutai Vikhe Patil College of Agriculture, Nashik during the year 2023-2024.

Methodology: The experiment involved sixteen treatment combinations with four replications. It was arranged in randomized block design with four different Pressure (P) with four levels are $P_1 = 1.0 \text{ kg/cm}^2$, $P_2 = 1.5 \text{ kg/cm}^2$, $P_3 = 2.0 \text{ kg/cm}^2$ and $P_4 = 2.5 \text{ kg/cm}^2$ and Spacing (S) with four levels $S_1 = 6 \text{ m} \times 6 \text{ m}$, $S_2 = 7 \text{ m} \times 7 \text{ m}$, $S_3 = 8 \text{ m} \times 8 \text{ m}$ and $S_4 = 9 \text{ m} \times 9 \text{ m}$.

Results: The index of jet break up was obtained in all the four operating pressures in the range of 2.24 to 4.1, however ideal value of index of jet break up was obtained close to 4.0 at 2.0 kg/cm^2 . The discharge rates were obtained as 235, 290, 330 and 365 lph at operating pressures of 1.0 kg/cm^2 , 1.5 kg/cm^2 , 2.0 kg/cm^2 and 2.5 kg/cm^2 respectively. Uniformity coefficient for all the system arrangements was in the range of 94.55 % to 92.34 %. The uniformity coefficients were obtained at par for $6 \text{ m} \times 6 \text{ m}$ spacing at 1.5 kg/cm^2 and $7 \text{ m} \times 7 \text{ m}$ spacing at 1.5 kg/cm^2 . Distribution uniformity was found in the range of 65.23 % to 84.10 %. Water spread area was obtained as 58.60 m^2 , 126.67 m^2 , 163.76 m^2 and 226.44 m^2 at operating pressures of 1.0 kg/cm^2 , 1.5 kg/cm^2 , 2.0 kg/cm^2 and 2.5 kg/cm^2 respectively. Mean application rate was in the range of 4.5 mm/h to 6.5 mm/h.

Conclusions: From the results obtained, the basis of performance systems of $6 \text{ m} \times 6 \text{ m}$ working at an operating pressure of 2.0 kg/cm^2 and 2.5 kg/cm^2 .

Keyword: Mini- Sprinkler, Jet break, Uniformity Coefficient, Distribution Uniformity and Mean application rate.

1. Introduction

The introduction of mini sprinkler irrigation represents a recent advancement in pressurized irrigation methods [16]. This approach addresses many of the challenges associated with conventional sprinkler and drip irrigation systems, either by eliminating them entirely or minimizing their impact [3]. One of the key advantages of mini sprinkler irrigation is its ability to provide low adjusted discharge while maintaining high uniformity of water application [8]. This ensures that water is distributed evenly across the field, mimicking natural rainfall and promoting optimal crop growth [11]. Studies have shown that the use of mini sprinklers in closely spaced crops and orchards can lead to increased yields and water savings compared to conventional irrigation methods [5]. By spreading water into the air and allowing it to fall onto the ground surface like rainfall, mini sprinkler systems effectively deliver water to the crop root zone [9].

The spray is generated through the flow of pressurized water through small openings, creating a uniform distribution pattern [18]. The primary objective of mini sprinkler irrigation is

to simulate rainfall and apply water evenly to the crop, thus enhancing irrigation efficiency [10]. Given the high-water requirements of intensively irrigated agricultural systems, such as rice-wheat sequences, there are concerns about the availability and quality of groundwater [20]. Mini sprinkler irrigation offers a potential solution by optimizing water use and reducing reliance on groundwater resources, thereby addressing these challenges [13]. Overall, the adoption of mini sprinkler irrigation holds promise for improving water efficiency, increasing crop yields, and mitigating the impact of intensive irrigation practices on groundwater resources [14]. Proper management and utilization of mini sprinkler systems can play a significant role in sustainable agricultural development [15].

Mini sprinkler irrigation is a versatile method of applying water above the soil surface, resembling natural rainfall through the dispersion of water via small nozzles [21]. This technique allows for precise control over the distribution of water, making it suitable for a wide range of crops [12]. By adjusting the spacing and overlap of sprinklers, farmers can tailor the irrigation to suit the specific needs of different soil types and crop varieties [15]. Unlike conventional sprinkler systems, which may suffer from uneven water distribution and excessive water loss due to evaporation and wind drift, mini sprinkler irrigation offers improved efficiency and uniformity of water application [19]. These findings underscore the potential of mini-sprinkler and drip irrigation technologies to enhance water use efficiency, increase crop yields, and improve financial returns, particularly in regions prone to water scarcity and drought [22]. As such, the adoption of these technologies can play a crucial role in sustainable agricultural development and water resource management [17].

2. MATERIALS AND METHODS

2.1 Location

The research experiment was conducted at Instructional Farm of Pravara's Sindhutai Vikhe Patil College of Agriculture, Nashik during the year 2023-2024.

2.2 Experimental setup

The mini sprinkler irrigation system set up was set with following components:

2.3 Statistical design

Randomized block design with four replication was adopted in the present investigation.

2.4 First Factor: Pressure (P) with three levels

- 1) 1.0 kg/cm²
- 2) 1.5 kg/cm²
- 3) 2.0 kg/cm²
- 4) 2.5 kg/cm²

Second Factor: Spacing (S) with three levels

- 1) 6 m X 6 m
- 2) 7 m X 7 m
- 3) 8 m X 8 m
- 4) 9 m X 9 m

Total Treatment combination: 16

Number of replications: 04

2.5 Water source: A sump well to supply water for a mini sprinkler irrigation system

2.6 Pump: A horizontal open well submersible pump of 10 HP coupled with an electric motor is an effective and efficient way to pump water from a sump well for various applications, including agricultural irrigation.

2.7 Mains and sub mains: A 90 mm (class II) PVC pipe was used to transfer irrigation water from the well to the field. The primary supply pipe for the tiny sprinkler irrigation system was connected to a separate PVC pipe measuring 63 mm in diameter, which was equipped with control valves.

2.8 Filter: i) **Sand filter:** Immediately upon delivery, a 25 m³/hr sand filter was installed.

ii) **Screen filter:** A 25 m³/hr screen filter was placed alongside a sand filter.

2.9 Pressure gauge: The pressure over the micro sprinkler will be measured using a dial pressure gauge with a range of 0 to 7 kg/cm².

2.10 Lateral lines: Through lateral lines, irrigation water was redirected from the submain line to the sprinkler head. The JISL (IS-12786) lateral line with a 25 mm diameter (class n, PE 25) was employed.

2.11 Anemometer: The anemometer was used to measure the wind velocity.

2.12 Mini Sprinkler assembly:

The “5022-4 Double Nozzle-full circle” small sprinkler irrigation company was used in the current study. It was installed on a 1.2 m long installation stake with an 8 mm ø sprinkler. The lateral was linked to the tiny sprinkler with a 1.2 m vinyl tube with a 12 mm inner diameter. There were two nozzles on the tiny sprinkler.

- Range nozzle (Light green): 1.8 mm Φ
- Spray nozzle (white): 1.8 mm Φ

Table 1 Manufacturers specifications of Mini Sprinkler

| Type of mini sprinkler | Nozzle colour | Operating pressure (kg/cm ²) | Discharge (lph) | Nozzle Diameter (mm) |
|------------------------|---------------|--|-----------------|----------------------|
| Double | Light green& | 1 | 235 | |
| Nozzle-full | White | 1.5 | 290 | 1.8& 1.8 |
| Circle | | 2 | 330 | |
| | | 2.5 | 365 | |

2.13 Resources and materials

The resources and materials which were required for conducting the experiment are briefed as below.

a) Water Resource

Water resources were obtained from a 30-centimeter-diameter tube well that was 75 meters deep overall. Throughout the season, the water level at the surface ranged from 10 to 20 meters.

b) Pumping system

The 7.5 HP X 6 stage X 3- Phase X 65 mm electric submersible motor was utilized to pump water out of the well. The delivery line was 65 mm in diameter and was made of GI.

c) Conveying pipe

The water was transported to the experiment site using the 110 mm X 4 kg/cm² (ISI) PVC pipe that was already in place.

2.14 Hydraulic evaluation of Mini Sprinklers:

The determination of sprinkler discharge (q), index of jet break up (Pd), Christiansen's uniformity coefficient (CU), distribution uniformity (DU), water spread area (A) and mean application rate (MAR), the mini sprinklers were evaluated at four different pressures of 1, 1.5, 2 and 2.5 kg/cm² and four different spacing arrangements of 6 m x 6 m, 7 m x 7 m, 8 m x 8 m and 9 m x 9 m.

2.15 Determination of Sprinkler discharge (q):

Sprinkler discharge is assessed by collecting the water emitted by the sprinkler into a bucket in a time interval of 2 minutes. By dividing the collected volume by the filling time, the discharge was computed. For every operating pressure, three discharge observations were made. The theoretical discharge of the sprinkler nozzle may be computed from the orifice flow equation.

$$q = C_d \times a \times \sqrt{2gh} \dots \dots \dots (1)$$

Where, q = Nozzle discharge, m³ /s (cubic meter per second),

a = Cross sectional area of sprinkler nozzle, m² (meter square),

h = Pressure head at the nozzle, m (meter),

C_d = Coefficient of discharge.

2.16 Determination of index of Jet breaks-up (Pd):

Slow rotation sprinklers, which make roughly 0.67 to 1 revolution per minute (rpm) for small sprinklers and 0.25 to 0.5 rpm for large sprinklers, gives decent coverage.

$$P_d = \frac{h}{10 \times q^{0.4}} \dots \dots \dots (2)$$

Where, P_d – index of jet breaks up,

h = pressure head at sprinkler nozzle, m (meter),

q = sprinkler discharge, lps (litres per second).

If value of P_d is greater than 2, the condition of drop size is considered to be good. If the value of P_d is 4, the condition of drop size is considered to be the best and if it is greater than 4 then pressure is being wasted.

2.17 Uniformity Coefficient

The average depth of water collected in the catch cans were used to compute Christiansen CU [23] for each test run of mini sprinkler system using the following equation:

$$CU = 100 \times \left[1 - \frac{\sum (X_i - X)}{NX} \right] \dots \dots \dots (3)$$

Where,

CU = coefficient of uniformity (%),

X_i = precipitation measured at any sample point,

X = mean precipitation and

n = number of observations.

2.18 Distribution Uniformity (DU):

It indicates the uniformity of water application throughout the field and is computed by

$$DU = \frac{\text{Minimum depth}}{\text{Average depth}} \times 100 \dots \dots \dots (4)$$

2.19 Mean application rate

The depth of water that a sprinkler applies to the soil surface in one unit of time is known as the mean application rate. To get the micro sprinkler's mean application rate, divide this volume by the cross-sectional area of the.

$$MAR = \frac{\sum X}{n \times t} \dots \dots \dots (5)$$

Where,

MAR = mean application rate (mm/h)

$\sum X$ = total depth of water collected in the catch cans (mm)

n = total number of catch cans

t = time of operation (h)

2.20 Determination of Radius and Area of Coverage

Effective Radius of the mini sprinkler was calculated using the boundary sprinklers of the experimental setup. The irrigation area covered by rotating head sprinkler was estimated by using the following formula.

$$A = \pi R^2 \dots \dots \dots (6)$$

in which $R = 1.35\sqrt{dh}$

Where, A = Area covered by the sprinkler, m²

R = Radius of wetted area covered by the sprinkler, m

d = Diameter of sprinkler nozzle, mm

h = Pressure head at the nozzle, m

2.21 Determination of Water Spread Area

Water spread area was calculated by using the effective radius of the mini sprinkler at the respective pressure and then the area was found using the formula:

$$A = \pi R^2$$

Where, A = Area covered by the sprinkler, m²

R = Radius of wetted area covered by the sprinkler, m

3. Results and Discussion

3.1 Determination of Discharge from mini sprinkler

The average discharge for a small sprinkler was ultimately calculated at different operating pressures and is shown in the table below. The relationship of discharge against operating pressure is shown in Fig. 1 and presented in Table 2.

Table 2 Determination discharge rate at various operating pressures for mini sprinkler

| Sr.No | Operating pressure (kg/cm ²) | Average Discharge (m ³ /h) |
|-------|--|---------------------------------------|
| 1 | 1 | 0.235 |
| 2 | 1.5 | 0.29 |
| 3 | 2 | 0.33 |
| 4 | 2.5 | 0.365 |

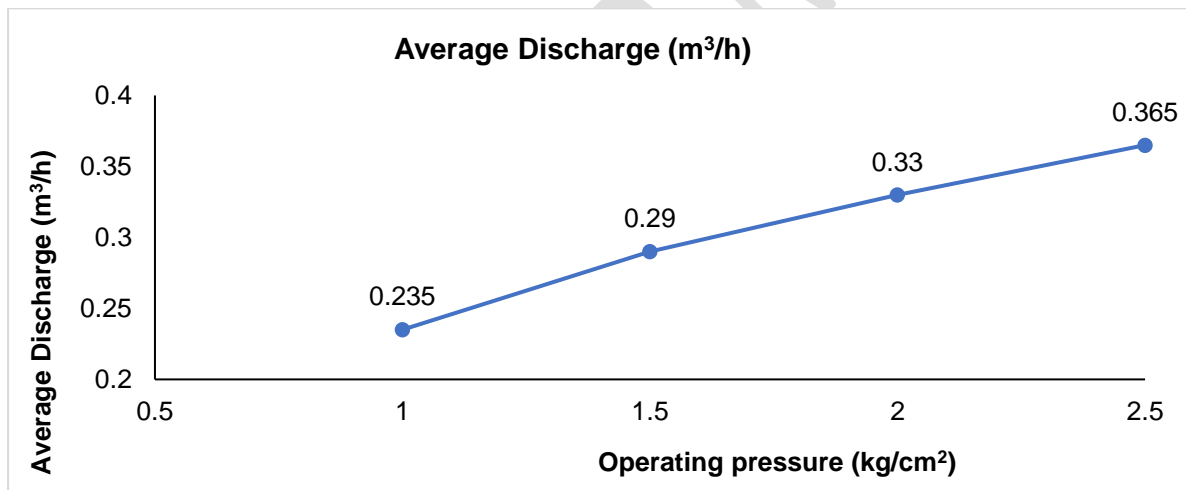


Fig. 1 Discharge of mini sprinkler at various operating pressure

As shown in Fig.1, the minimum and maximum discharge of 0.235 m³/h and 0.365 m³/h were obtained at pressures 1 kg/cm² and 2.5 kg/cm² respectively. As the pressure increases from 1.0 kg/cm² to 2.5 kg/cm², there is a significant rise in the discharge. However, it can be noted from the figure that the rate of increase in discharge is reduced as the pressure increased from 1.0 to 2.5 kg/cm². The maximum discharge of 0.365 m³/hr was observed for nozzle at operating pressure of 2.5 kg/cm². Data presented in Table 2 shows the minimum discharges were observed at operating pressure of 1.0 kg/cm² and the maximum discharges were observed at operating pressure of 2.5 kg/cm². This reveals that the discharge of nozzle increases with increase in operating pressure.

3.2 Determination of index of Jet breaks-up (Pd):

The mini sprinkler was operated at 1.0, 1.5, 2.0 and 2.5 kg/cm² pressure and the values of pressure head and average discharge at the mini sprinkler nozzle were obtained which were used in the empirical equation 2 to obtain the index of jet break up presented in Table 3 and Fig. 2.

Table 3 Determination of index of Jet break-up at various operating pressure

| Sr. No. | Operating Pressure (kg/cm ²) | Index of Jet break up |
|---------|--|-----------------------|
| 1 | 1 | 2.24 |
| 2 | 1.5 | 2.9 |
| 3 | 2 | 3.6 |
| 4 | 2.5 | 4.1 |

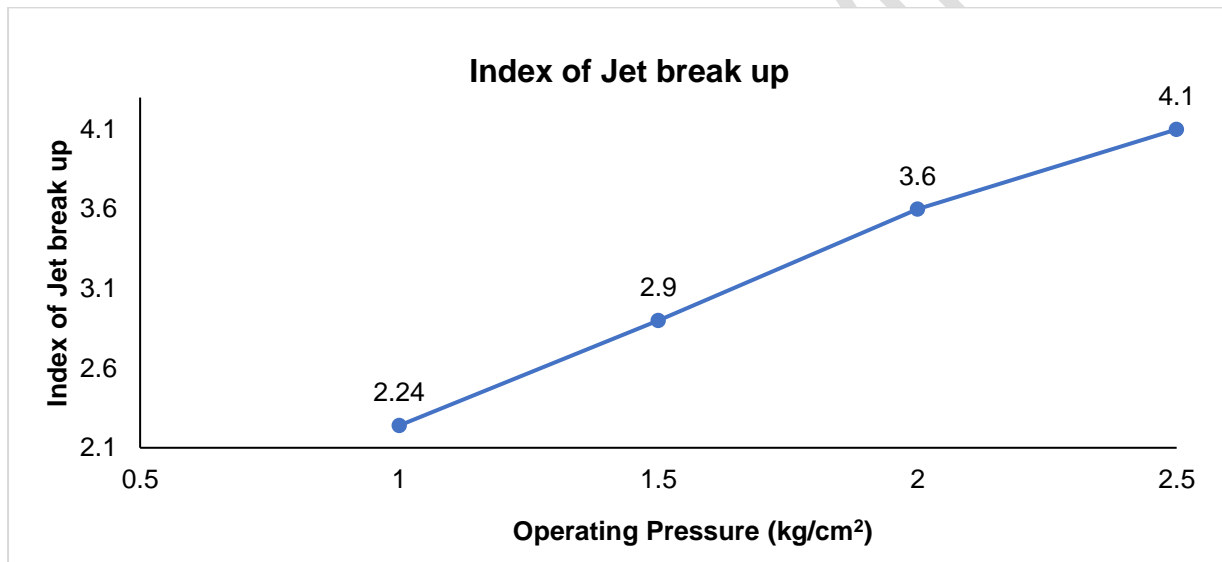


Fig. 2 Index of Jet break up at various pressures of mini sprinkler

As Shown in Fig. 2 when the pressure was maintained at 2.0 kg/cm² the value of index of jet break up was found to be 3.6. This value of index of jet breaks up near to 2.0 kg/cm² indicates that the droplet size is not good at the pressure of 2.5 kg/cm². The value of index of jet breaks up when the pressure was maintained at 2.0 kg/cm² was found to be 3.6 which is very well in between 2.00 and 4.00 values and so it is an indication of good droplet size. The droplet size is considered best if the value of index of jet break up is 4. However, it was found that the value of index of jet break up (4.10) at 2.5 kg/cm² pressure was found to be exceeding the value of 4 which clearly indicated that the pressure was being wasted.

3.3 Uniformity Coefficient

The mini sprinkler was operated at pressures of 1.0 kg/cm², 1.5 kg/cm², 2.0 kg/cm² and 2.5 kg/cm². Catch cans were placed at 2 m distance in the grid surrounded by mini sprinkler and

the amount of water collected in it for a specific period of time was recorded to obtain the uniformity coefficient.

Table 4 Uniformity Coefficient at various operating pressures and spacing of mini sprinklers spacing's

| Operating Pressure (kg/cm ²) | Spacing (m) | Uniformity Coefficient (%) |
|--|-------------|----------------------------|
| 1 | 6 m X 6 m | 86.54 |
| | 7 m X 7 m | 85.4 |
| | 8 m X 8 m | 91.12 |
| | 9 m X 9 m | 84.56 |
| 1.5 | 6 m X 6 m | 89.13 |
| | 7 m X 7 m | 88.06 |
| | 8 m X 8 m | 92.00 |
| 2 | 9 m X 9 m | 86.00 |
| | 6 m X 6 m | 92.32 |
| | 7 m X 7 m | 91.11 |
| | 8 m X 8 m | 93.23 |
| 2.5 | 9 m X 9 m | 89.00 |
| | 6 m X 6 m | 94.55 |
| | 7 m X 7 m | 94.00 |
| | 8 m X 8 m | 95.00 |
| | 9 m X 9 m | 92.34 |

As Shown in Fig. 3 Uniformity obtained at sprinkler spacing of 6 m × 6 m is also more than 80 % at different operating pressure and lower number of mini sprinklers will be required if the setup is to be done in an area of one hectare or more. Therefore, the sprinkler spacing of 6 m × 6 m will be beneficial from economic point of view as well and there is not a drastic reduction in uniformity in comparison to the mini sprinkler spacing of 6 m × 6 m. The value of uniformity is considerably lower at the spacing of 9 m × 9 m especially at lower operating pressure so it should not be recommended. Considering optimal pressure to be 2.5 kg/cm² and the spacing to be 8 m × 8 m, the uniformity coefficient of 95.00 % can be obtained.

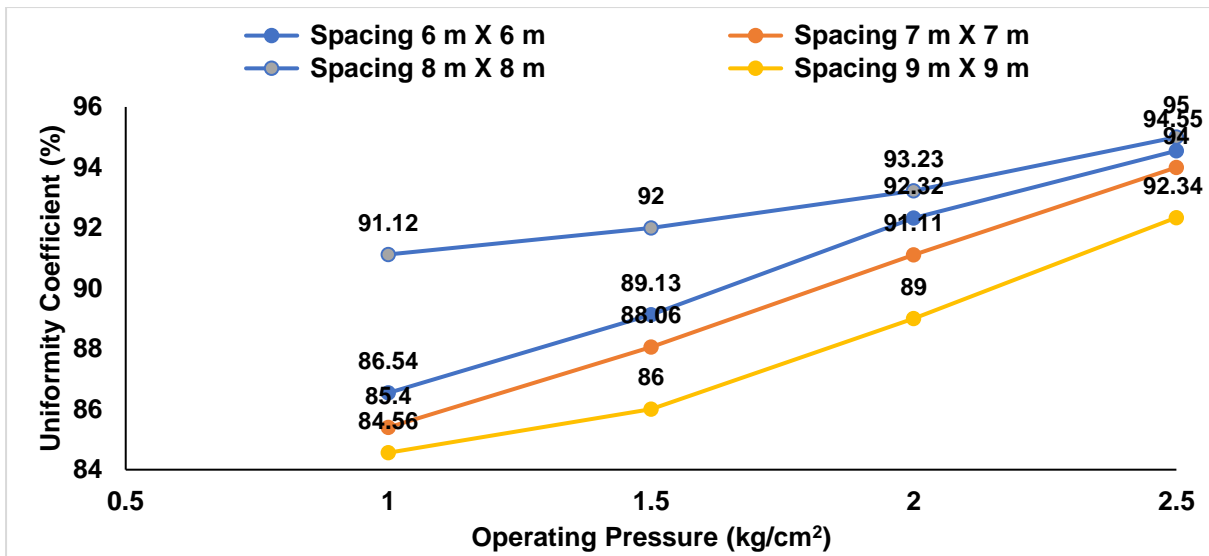


Fig. 3. Uniformity Coefficient at various operating pressures

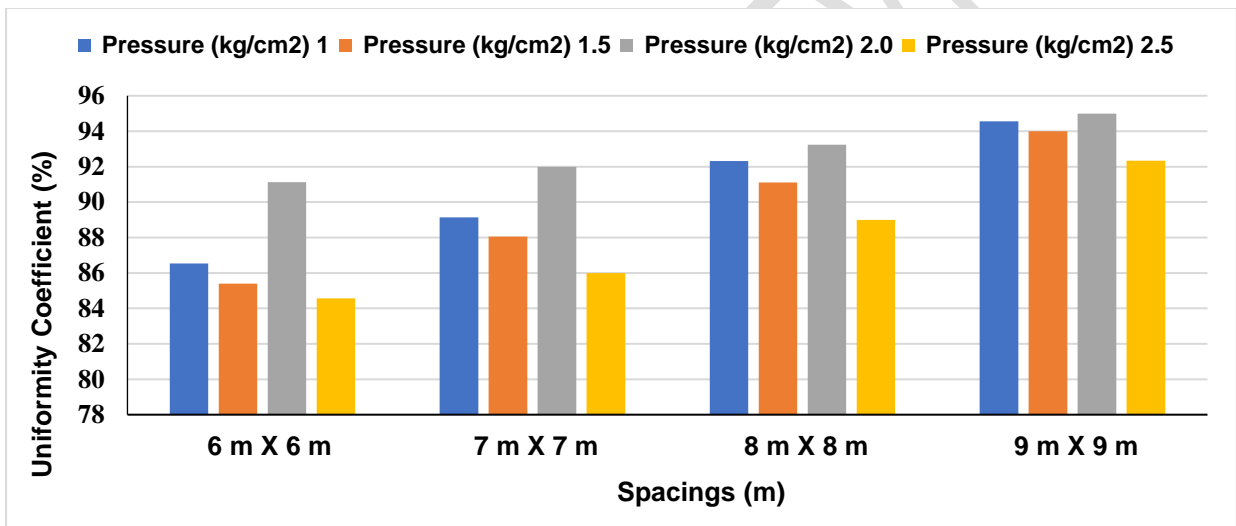


Fig.4 Uniformity Coefficient at various spacing's (%)

3.4 Distribution Uniformity (DU)

The mini sprinkler was operated at pressure of 1.0 kg/cm², 1.5 kg/cm², 2.0 kg/cm² and 2.5 kg/cm². Catch can were placed at 2 m distance in the grid surrounded by mini sprinklers and the amount of water collected in it for a specific period of time was noted to obtain the distribution uniformity.

Table 5 Distribution Uniformity at various operating pressures and spacing of mini sprinklers spacing's

| Operating Pressure (kg/cm ²) | Spacing (m) | Distribution Uniformity (%) |
|--|-------------|-----------------------------|
| 1 | 6 m X 6 m | 65.23 |
| | 7 m X 7 m | 69.1 |
| | 8 m X 8 m | 71.12 |

| | | |
|-----|-----------|-------|
| | 9 m X 9 m | 73.23 |
| | 6 m X 6 m | 69.34 |
| 1.5 | 7 m X 7 m | 72.2 |
| | 8 m X 8 m | 74.21 |
| | 9 m X 9 m | 75.12 |
| | 6 m X 6 m | 74.54 |
| 2 | 7 m X 7 m | 76.34 |
| | 8 m X 8 m | 76.5 |
| | 9 m X 9 m | 89 |
| | 6 m X 6 m | 78.2 |
| 2.5 | 7 m X 7 m | 79.05 |
| | 8 m X 8 m | 82 |
| | 9 m X 9 m | 84.1 |

As shown in Fig.5, the highest value of distribution uniformity was obtained when the spacing mini sprinkler was kept at 6 m ×6 m and the pressure was 2.5 kg/cm². The lowest value of distribution uniformity coefficient was obtained at the spacing of 9 m ×9 m and the pressure was 1.0 kg/cm². Statistically significant difference between the treatments. Fig.6 clearly indicated that as the spacing between the mini sprinklers increased there was reduction in the value of distribution uniformity coefficient and vice versa.

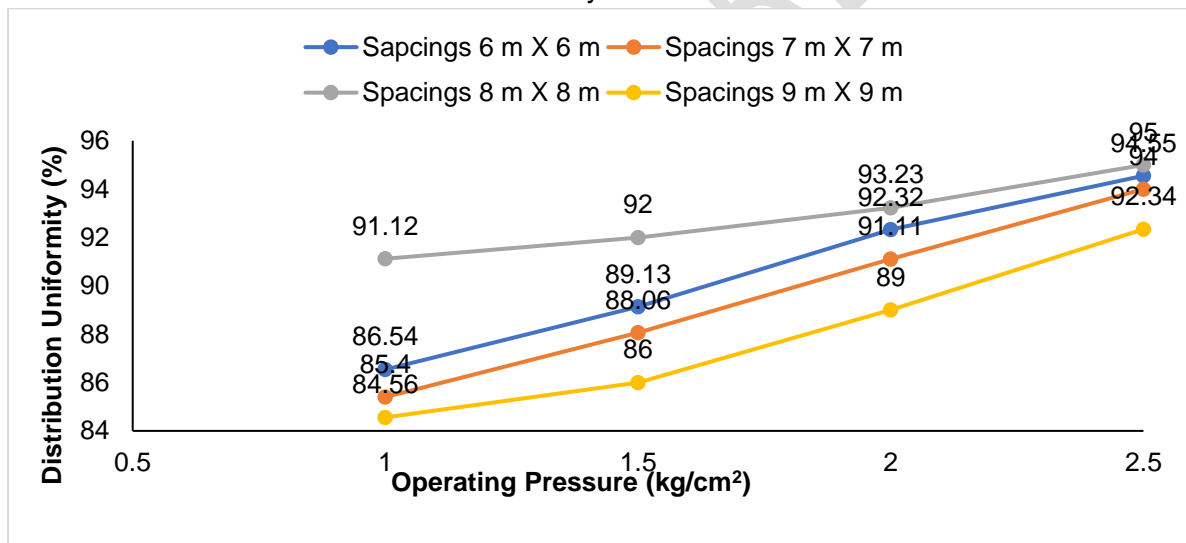


Fig.5 Distribution Uniformity at various operating pressures

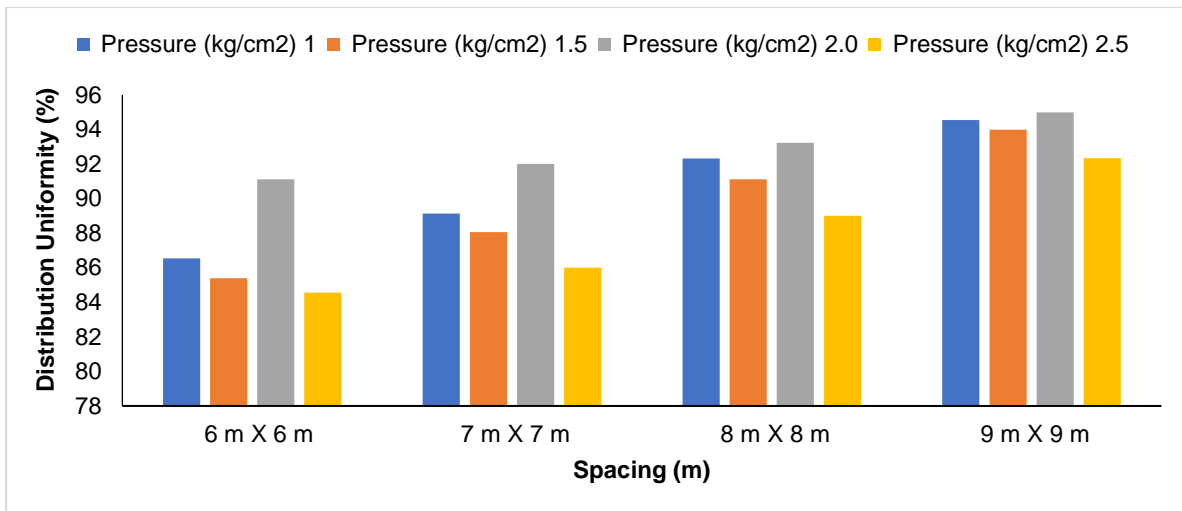


Fig. 6 Distribution Uniformity at various spacing's

The distribution uniformity obtained at sprinkler spacing of 7 m × 7 m is near 80 % at different operating pressures and lesser number of mini sprinklers required if the setup is to be done in an area of one hectare or more. The value of distribution uniformity is considerably lower at the spacing of 9 m × 9 m especially at lower operating pressure so it cannot be recommended. Considering optimal pressure to be 2.5 kg /cm² and the spacing to be 9 m x 9 m, the distribution uniformity coefficient of 84.01 % can be obtained.

3.5 Mean application rate

Application rate at various operating pressures and spacing's were obtained during the experiment and its values are presented in Table 6.

Table 6 Application rate of mini sprinkler at various operating pressures and spacings

| Operating Pressure (kg/cm ²) | Spacing (m) | Application rate (mm/hr) |
|--|-------------|--------------------------|
| 1 | 6 m X 6 m | 6.5 |
| | 7 m X 7 m | 4.8 |
| | 8 m X 8 m | 3.7 |
| | 9 m X 9 m | 2.9 |
| 1.5 | 6 m X 6 m | 8.1 |
| | 7 m X 7 m | 5.9 |
| | 8 m X 8 m | 4.5 |
| | 9 m X 9 m | 3.6 |
| 2 | 6 m X 6 m | 9.2 |
| | 7 m X 7 m | 6.7 |
| | 8 m X 8 m | 5.2 |
| | 9 m X 9 m | 4.1 |
| 2.5 | 6 m X 6 m | 10.1 |
| | 7 m X 7 m | 7.4 |
| | 8 m X 8 m | 5.7 |
| | 9 m X 9 m | 4.5 |

As shown Fig 7 and Fig 8, the maximum application rate is obtained at the spacing of 6 m x 6 m and operating pressure of 2.5 kg/cm² and least application rate is obtained at 7 m x 7 m spacing and operating pressure of 1.5 kg/cm². To obtain better application rates at higher spacing's, the operating pressure will have to be increased. There is a considerable difference in application rate if the pressure is lowered. If low operating pressure is available, it is advisable to keep the spacing as low as possible in order to obtain higher application rates. For example, the application rate at spacing of 6 m x 6 m even at low operating pressure of 1 kg/cm² is 6.5 mm/h. The application rate of 7.4 mm/h was obtained even at 7 m x 7 m spacing when the operating pressure was maintained at 2.5 kg/cm².

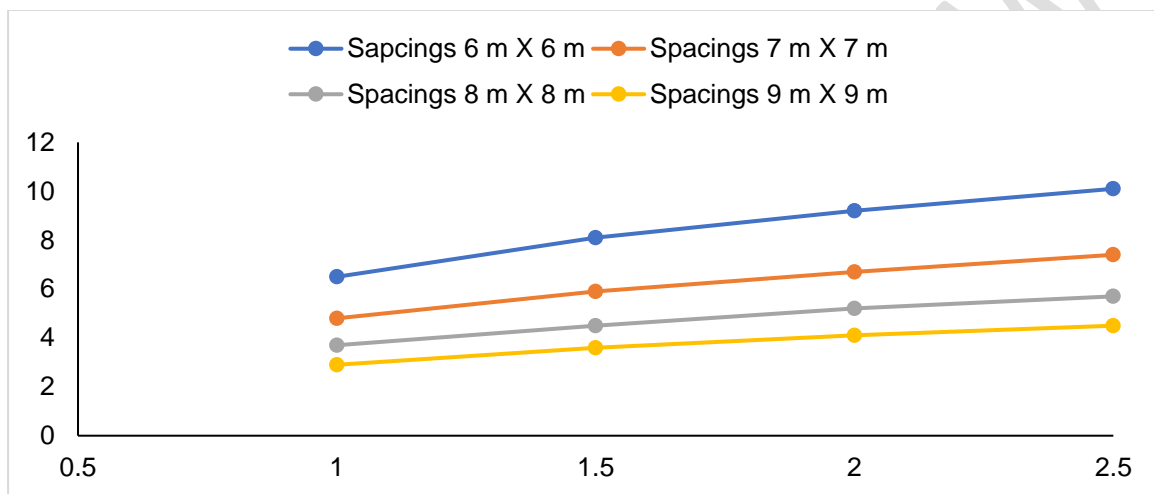


Fig 7 Application rate at various operating pressures

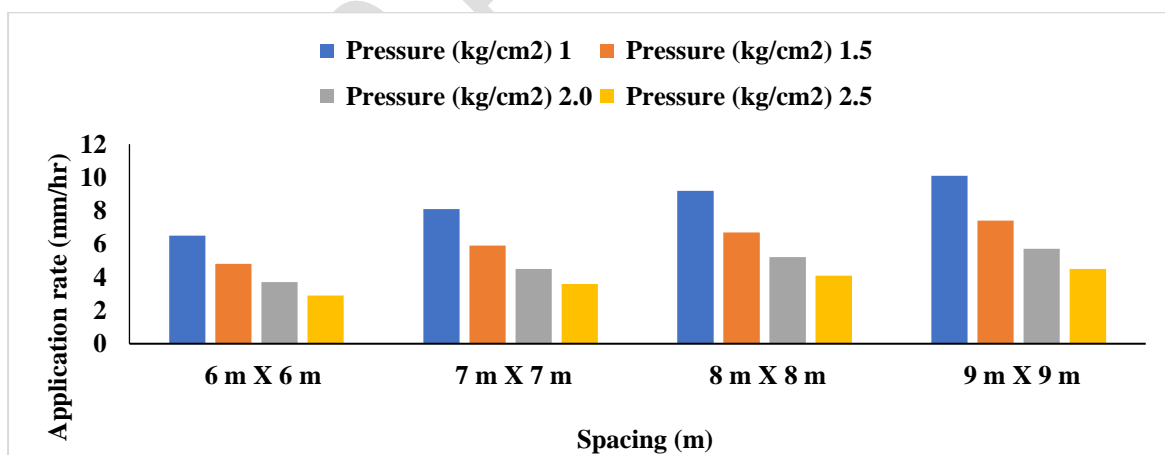


Fig 8 Application rate at various sprinkler spacing's

3.6 Determination of Radius and Area of Coverage

The radius and area of coverage were measured around the mini sprinklers and its average values are presented in Table 7.

Table 7 Radius and area of coverage of mini sprinkler at various operating pressures

| Sr. No. | Operating Pressure (kg/cm ²) | Radius of Coverage (m) | Area of Coverage (m ²) |
|---------|--|------------------------|------------------------------------|
| 1 | 1 | 4.32 | 58.60 |
| 2 | 1.5 | 6.35 | 126.67 |
| 3 | 2 | 7.22 | 163.76 |
| 4 | 2.5 | 8.49 | 226.44 |

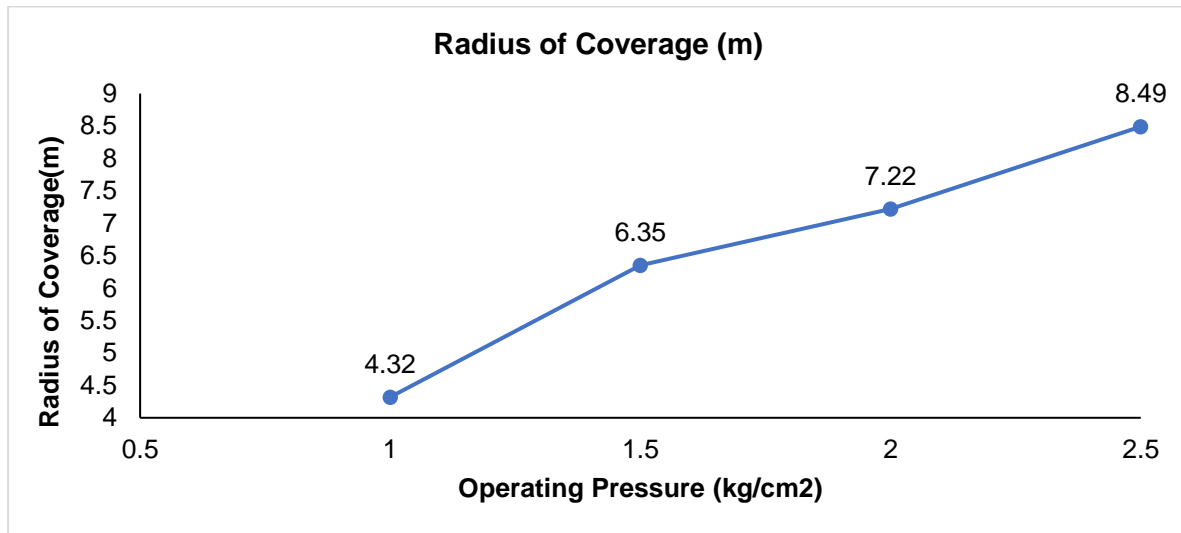


Fig.9 Radius of coverage of mini sprinkler at various operating pressures

As shown in Fig 9, the least radius of coverage was obtained when the mini sprinkler was operated at the pressure of 1.0 kg/cm² and maximum radius of coverage is obtained when the mini sprinkler is operated at the pressure of 2.5 kg /cm². The difference between the maximum and minimum radius of coverage is 4.32 metres. At the pressure of 2.0 kg/cm², the radius of coverage obtained is 7.22 metres which is just 1.27 metres less the value obtained at maximum operating pressure of 2.5 kg /cm². Similarly, as shown in the figure the least area of coverage was obtained when the mini sprinkler is operated at the pressure of 1.5 kg /cm² and maximum area of coverage is obtained when the mini sprinkler is operated at the pressure of 2.5 kg /cm². The difference between the maximum and minimum area of coverage is 58.60 square metres. At the pressure of 2.0 kg/cm², the area of coverage obtained is 163.76 square meters.

Conclusions

- 1) The index of jet break-up varied from 2.24 to 4.1 as the operating pressure increased from 1.0 kg/cm² to 2.5 kg/cm², respectively.
- 2) The discharge rates were obtained as 235, 290, 330 and 365 lph at operating pressures of 1.0 kg/cm², 1.5 kg/cm², 2.0 kg/cm² and 2.5 kg/cm² respectively.

- 3) Uniformity coefficient for all the systems was in the range of 94.55 % to 92.34 %. Uniformity coefficient was higher than 80 % in all the case except for 6 m x 6 m arrangement operating at a pressure of 1.5 kg/cm².
- 4) Distribution uniformity was found in the range of 65.23 % to 84.10 %. The sprinkler arrangements 9 m x 9 m at operating pressure of 2 kg/cm², 2.5 kg/cm² and 7 m x 7 m at 1.5 kg/cm² have distribution uniformity less than 70 % and were considered inefficient.
- 5) Effective radius of throw of the mini sprinklers was obtained as 4.32 m, 6.35 m, 7.22 m and 8.49 m at operating pressures of 1.0 kg/cm², 1.5 kg/cm², 2.0 kg/cm² and 2.5 kg/cm² respectively.
- 6) Water spread area was obtained as 58.60 m², 126.67 m², 163.76 m² and 226.44 m² at operating pressures of 1.0 kg/cm², 1.5 kg/cm², 2.0 kg/cm² and 2.5 kg/cm² respectively.
- 7) Mean application rate was in the range of 4.5 mm/h to 6.5 mm/h.

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