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Performance Evaluation of Mini-sprinkler Irrigation System Underdifferent Pressures and Spacings

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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ABSTRACT

The hydraulic performance of a small sprinkler system was assessed in the current study. A small sprinkler system with a "double nozzle - full circle" sprinkler was used in the experiment to assess the hydraulic performance. It was arranged in randomized block design.The research experiment was conducted at Instructional Farm of Pravara's Sindhutai Vikhe Patil College of Agriculture, Nashik during the year 2023-2024. 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 kg/cm^2, P_2 = 1.5 kg/cm^2, P_3 = 2.0 kg/cm^2 and P_4 = 2.5 kg/cm^{2}and Spacing (S) with four levels S_1 = $6m \times 6\,m$, S_2 = 7 m × 7 m, S_3 = 8 m × 8 m and S_4 = 9 m × 9 m. Although the optimum value of the index of jet break up was near 4.0 at 2.0 kg/cm^2, the index of jet break up was obtained in the range of 2.24 to 4.1 for all four working pressures. The discharge rates were

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obtained as 235, 290, 330 and 365lph 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. At each set up, the uniformity coefficient ranged between 94.55 % and 92.34 %. For 6 m × 6 m spacing at 1.5 kg/cm^2 and 7 m x 7 m spacing at 1.5 kg/cm^2, the uniformity coefficients were at par. Uniformity of distribution was discovered within 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/cm2, 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. From the results obtained, the basis of performance systems of6 m x 6 m working at an operating pressure of 2.0 kg/cm^2 and 2.5 kg/cm^2.

Keywords: Mini- sprinkler; Jet break; uniformity coefficient; distribution uniformity and mean application rate.

1. INTRODUCTION

Mini sprinkler irrigation is a versatile method for spreading water on soil above the surface, resembling natural rainfall through the dispersion of water via small nozzles (Singh et al., 2001). This technique allows for precise control over the distribution of water, making it suitable for a wide range of crops (Liu et al., 2013). 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 (Osman et al., 2014). 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 (ShaikhL 2008). The introduction of mini sprinkler irrigation represents a recent advancement in pressurized irrigation methods (Patel et al., 2021). This approach addresses many of the challenges associated with conventional sprinkler and drip irrigation systems, either by eliminating them entirely or minimizing their impact (Chandrakar and Pandey 2018). One of the key advantages of mini sprinkler irrigation is its ability to provide low adjusted discharge while maintaining high uniformity of water application (Grewal et al., 2021).

This ensures that water is distributed evenly across the field, mimicking natural rainfall and promoting optimal crop growth (Keskar et al., 2023). 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 (Dukes 2006). 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 (Gutal et al., 1989). The spray is generated through the flow of pressurized water through small openings, creating a uniform distribution pattern (Sahin et al., 2005). The primary objective of mini method for spreading water on soil above the surface water evenly to the crop, thus enhancing irrigation efficiency (Kadam and Gorantiwar 2009). 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 (Shete and Modi 1995). Mini sprinkler irrigation offers a potential solution by optimizing water use and reducing reliance on groundwater resources, thereby addressing these challenges (Mantovani et al., 1995).

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 (Nasab et al., 2007, Bhagwat et al., 2024). Proper management and utilization of mini sprinkler systems can play a significant role in sustainable agricultural development (Osman et al., 2014). 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 (Wilson and Zoldoske 1997). As such, the adoption of these technologies can play a crucial role in sustainable agricultural development and water resource management (Pawar et al., 2002).

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 (Bansod 2002).

2.2 Experimental Setup

The following elements were used to set up the small sprinkler irrigation system:

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/cm^2
2) 1.5 kg/cm^2
3) 2.0 kg/cm^2
4) 2.5 kg/cm^2

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 (Bhagwat et al., 2023).

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 (Dukes 2006).

2.8 Filter

i) Sand filter: Immediately upon delivery, a 25 m^3/hr sand filter was installed.

ii) Screen filter: A 25 m^3/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/cm^2.

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 æ 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 (Dwivediet al., 2015).

- 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 Nozzle-full Circle	Light green& White	1	235	1.8 & 1.8
		1.5	290	
		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 mini sprinklers was evaluated at four different pressures of 1, 1.5, 2, and 2.5 kg/cm^2 and four different spacing arrangements of 6 m × 6 m, 7 m × 7 m, 8 m × 8 m, and 9 m × 9 m. The following data were measured: 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).

2.15 Determination of Sprinkler Discharge (q)

The process of measuring sprinkler discharge involves collecting the water that the sprinkler emits into a container every two minutes. The discharge was calculated by dividing the collected volume by the filling time. Three discharge observations were performed for each operational pressure. The orifice flow equation can be used to calculate the sprinkler nozzle's theoretical discharge (Frank 2009).

$$q = Cd \times a \times \sqrt{2gh} \tag{1}$$

Where, q = Nozzle discharge, m^3 /s (cubic meter per second),

a = Cross sectional area of sprinkler nozzle, m^2 (meter square),

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

Cd = Coefficient of discharge.

2.16 Determination of Index of Jet Breaks-up (Pd)

Adequate coverage is provided by slow rotation sprinklers, which generate between 0.67 and 1 revolution per minute (rpm) for small sprinklers and 0.25 and 0.5 rpm for large sprinklers.

$$P_d = \frac{h}{10 \text{ X } q0.4} \tag{2}$$

Where, Pd – index of jet breaks up,

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

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

A drop size is deemed to be in acceptable condition if the Pd value is larger than 2. If the Pd number is 4, the drop size condition is deemed optimal; if it is higher than 4, pressure is being wasted.

2.17 Uniformity Coefficient

The average depth of water collected in the catch cans were used to compute Christiansen CU (Christiansen 1941) for each test run of mini sprinkler system using the following equation:

$$CU = 100 \text{ x } [1 - \frac{\varepsilon i(Xi-X)}{NX}] \tag{3}$$

Where,
CU = coefficient of uniformity (%),
Xi = 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

$$DU = \frac{Minimumdepth}{Averagedepth} \times 100 \tag{4}$$

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.

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

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

Using the experimental setup's boundaries sprinklers, the tiny sprinkler's effective radius was determined. The following calculation was used to determine the watering area that a rotating head sprinkler should cover.

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

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

Where, A = Area covered by the sprinkler, m^2

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

The effective radius of the micro sprinkler at the appropriate pressure was used to determine the water spread area, and the following formula was then used to find the area:

$$A = \pi R^2$$

Where, A = Area covered by the sprinkler, m^2

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 2 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

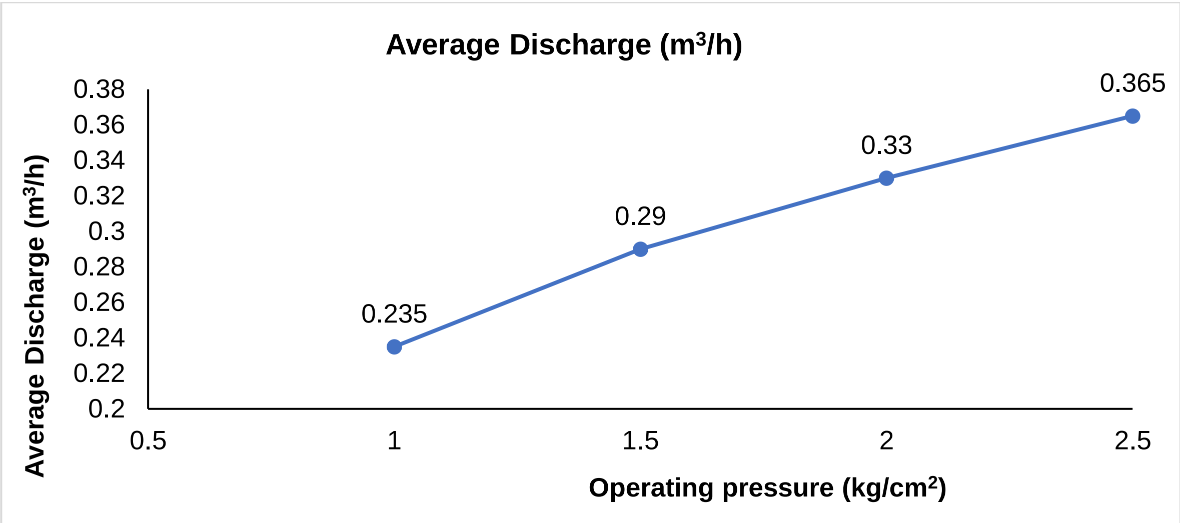

Fig. 1. Discharge of mini sprinkler at various operating pressure

At pressures of 1 kg/cm^2 and 2.5 kg/cm^2, respectively, the lowest and maximum discharges of 0.235 m^3/h and 0.365 m^3/h occurred as shown in Fig. 1. The discharge increases significantly as the pressure rises from 1.0 kg/cm^2 to 2.5 kg/cm^2. However, the Fig. 1 shows that when the pressure reached from 1.0 to 2.5 kg/cm^2, the rate of rise in discharge decreased. At an operating pressure of 2.5 kg/cm^2, the nozzle's maximum discharge of 0.365 m^3/hr was recorded. Data presented in Table 2 shows the minimum discharges were observed at operating pressure of 1.0 kg/cm^2 and the maximum discharges were observed at operating pressure of 2.5 kg/cm^2. 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/cm^2 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.

As Shown in Fig. 2 when the pressure was maintained at 2.0 kg/cm^2 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/cm^2 indicates that the droplet size is not good at the pressure of 2.5 kg/cm^2. The value of index of jet breaks up when the pressure was maintained at 2.0 kg/cm^2 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/cm^2 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/cm^2, 1.5 kg/cm^2, 2.0 kg/cm^2 and 2.5 kg/cm^2. 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 3. Determination of index of Jet break-up at various operating pressure

Sr. No.	Operating Pressure (kg/cm2)	Index of Jet break up
1	1	2.24
2	1.5	2.9
3	2	3.6
4	2.5	4.1

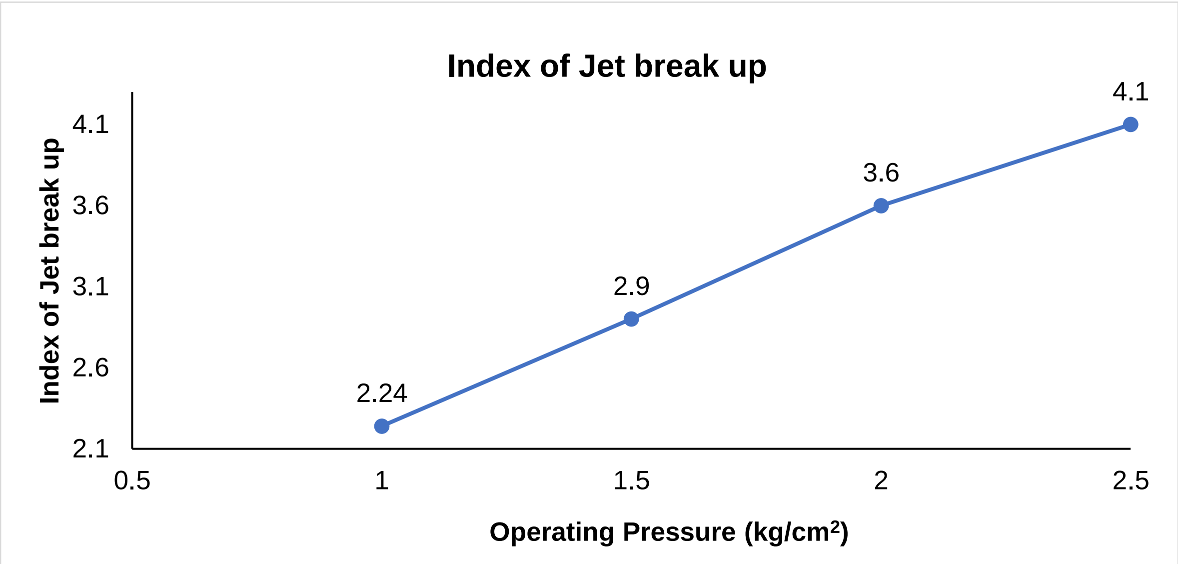

Fig. 2. Index of Jet break up at various pressures of mini sprinkler

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
	6 m X 6 m	89.13
1.5	7 m X 7 m	88.06
	8 m X 8 m	92.00
	9 m X 9 m	86.00
	6 m X 6 m	92.32
2	7 m X 7 m	91.11
	8 m X 8 m	93.23
	9 m X 9 m	89.00
2.5	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

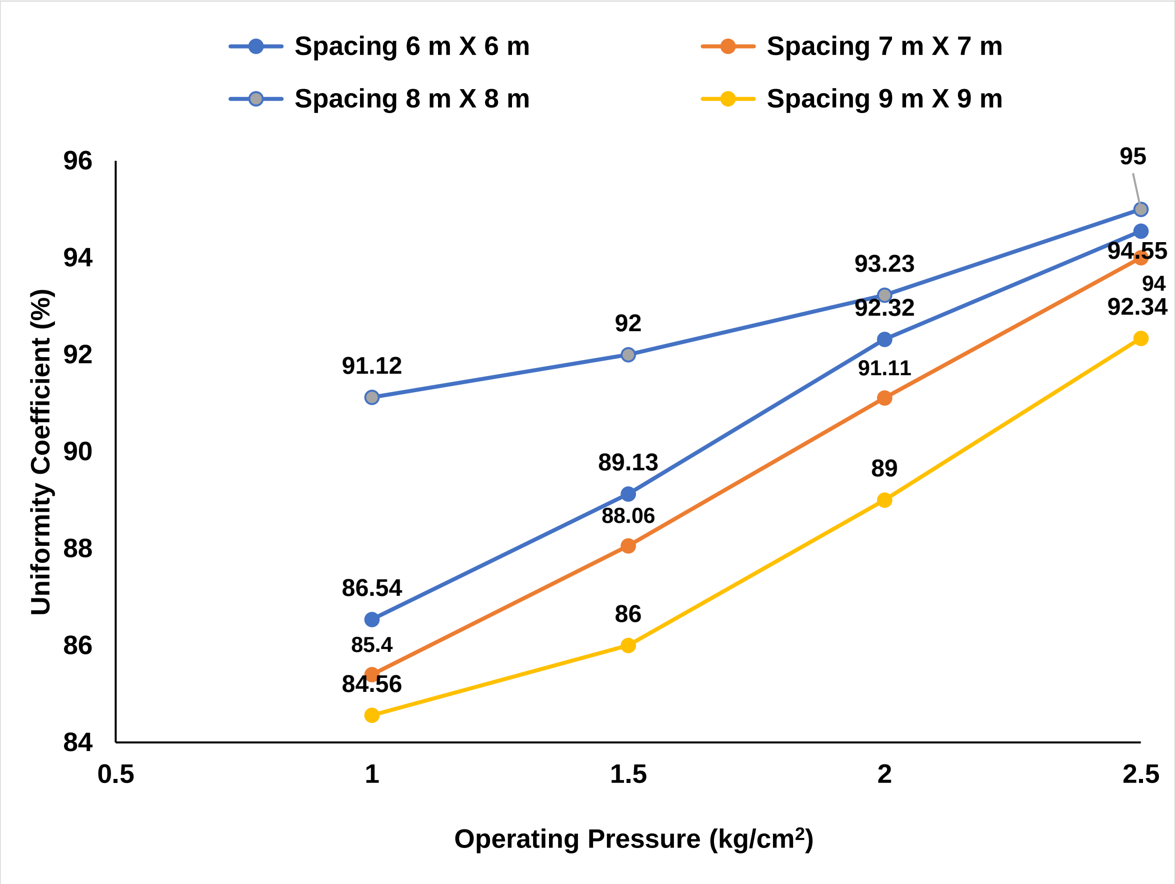

Fig. 3. Uniformity Coefficient at various operating pressures

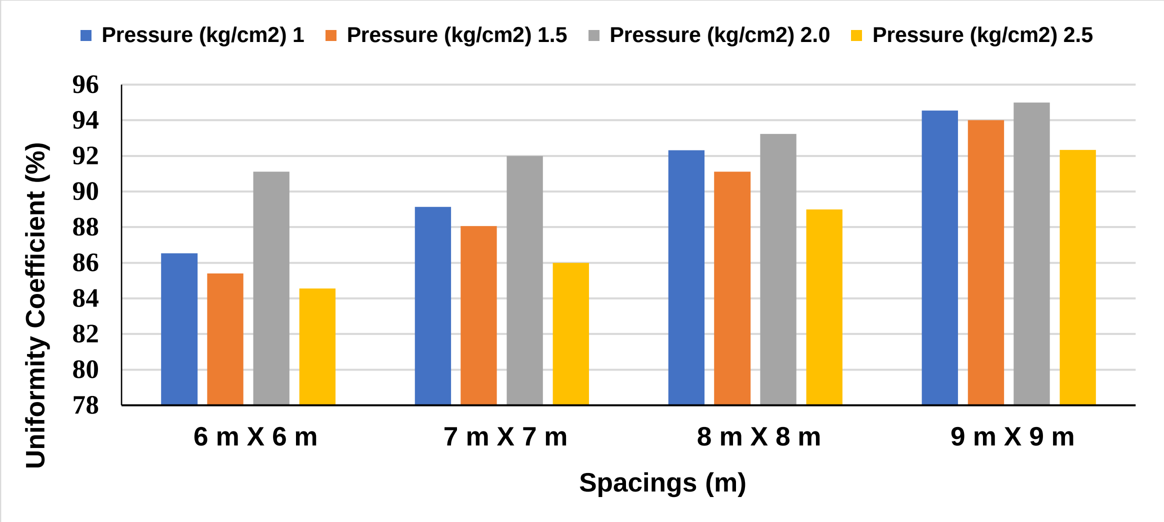

Fig. 4. Uniformity Coefficient at various spacing's (%)

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

Operating Pressure (kg/cm2)	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
	7 m X 7 m	72.2
1.5	8 m X 8 m	74.21
	9 m X 9 m	75.12
	6 m X 6 m	74.54
	7 m X 7 m	76.34
2	8 m X 8 m	76.5
	9 m X 9 m	89
2.5	6 m X 6 m	78.2
	7 m X 7 m	79.05
	8 m X 8 m	82
	9 m X 9 m	84.1

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. As a result, the 6 m × 6 m sprinkler spacing will also be advantageous economically, and there won't be a significant drop in uniformity as compared to the 6 m × 6 m small sprinkler spacing. It should not be advised because the uniformity value is significantly lower at 9 m x 9 m spacing, particularly at lower operating pressure. With a spacing of 8 m × 8 m and an ideal pressure of 2.5 kg/cm2, a 95.00% uniformity coefficient can be achieved.

3.4 Distribution Uniformity (DU)

The mini sprinkler was operated at pressure of 1.0 kg/cm^2, 1.5 kg/cm^2, 2.0 kg/cm^2 and 2.5 kg/cm^2. 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.

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/cm^2. At 9 m x 9 m spacing and 1.0 kg/cm2 of pressure, the distribution uniformity coefficient had the lowest value. The differences between the treatments are statistically significant. Fig. 6 made it abundantly evident that the distribution uniformity coefficient value decreased as the distance between the mini sprinklers rose and vice versa.

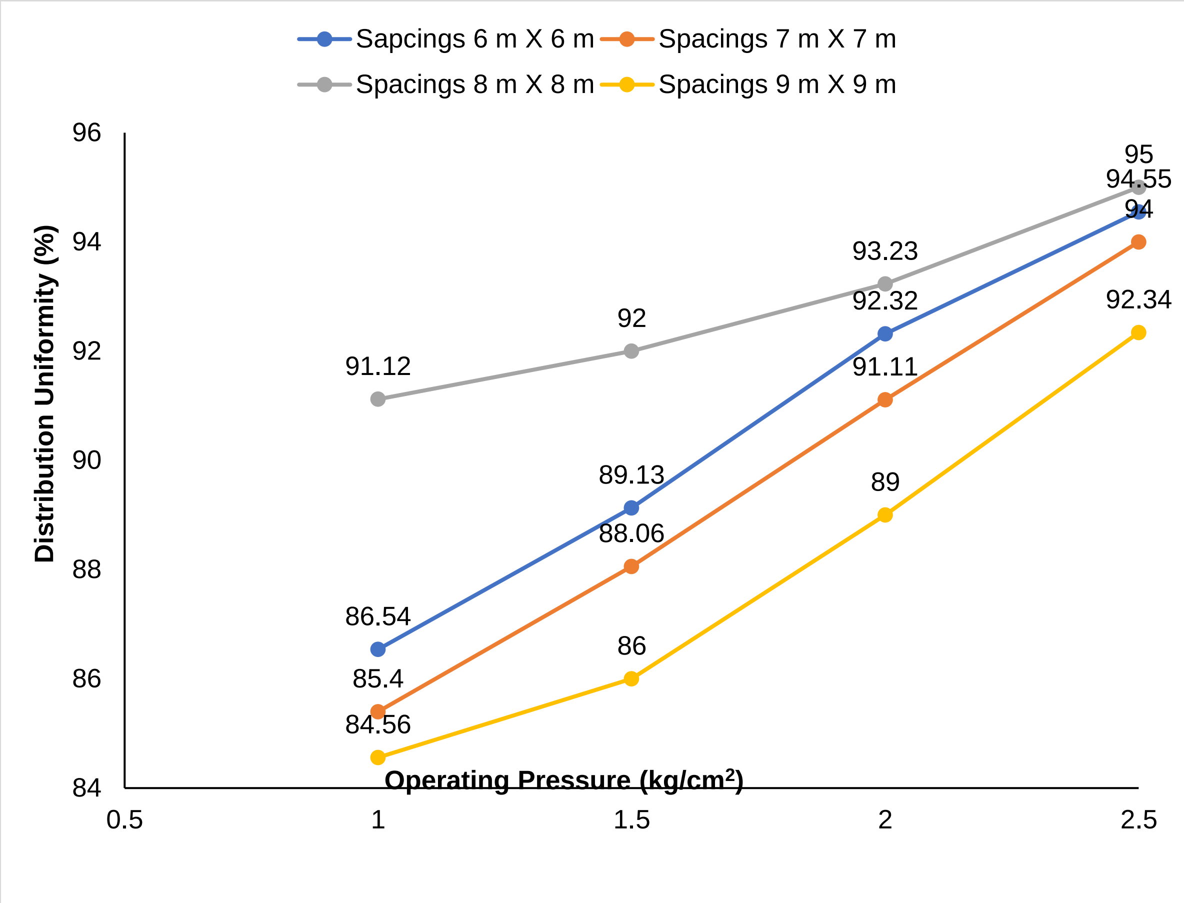

Fig. 5. Distribution Uniformity at various operating pressures

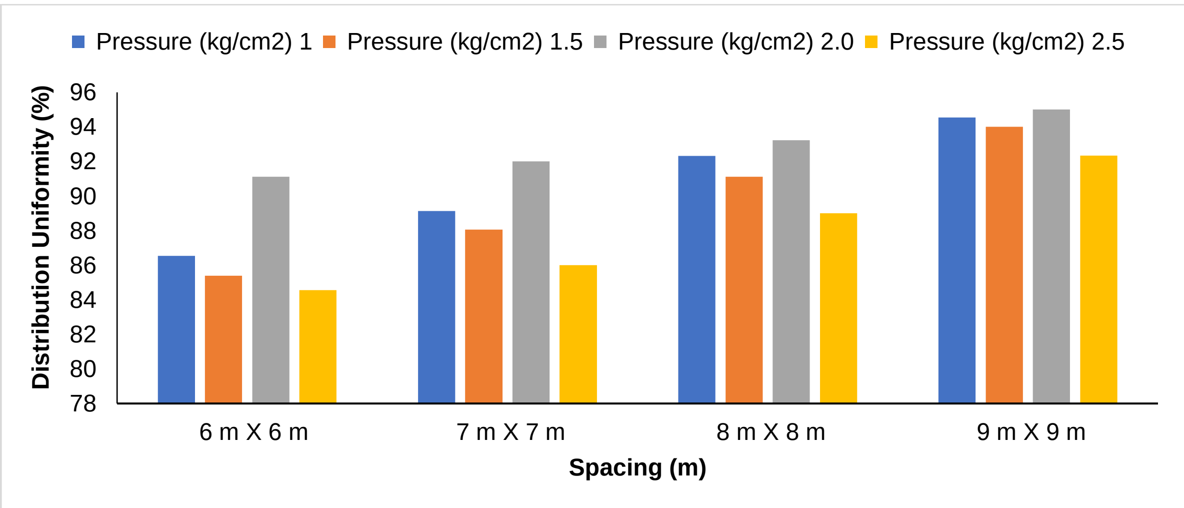

Fig. 6. Distribution Uniformity at various spacing's

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

Operating Pressure (kg/cm2)	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
	6 m X 6 m	8.1
1.5	7 m X 7 m	5.9
	8 m X 8 m	4.5
	9 m X 9 m	3.6
	6 m X 6 m	9.2
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

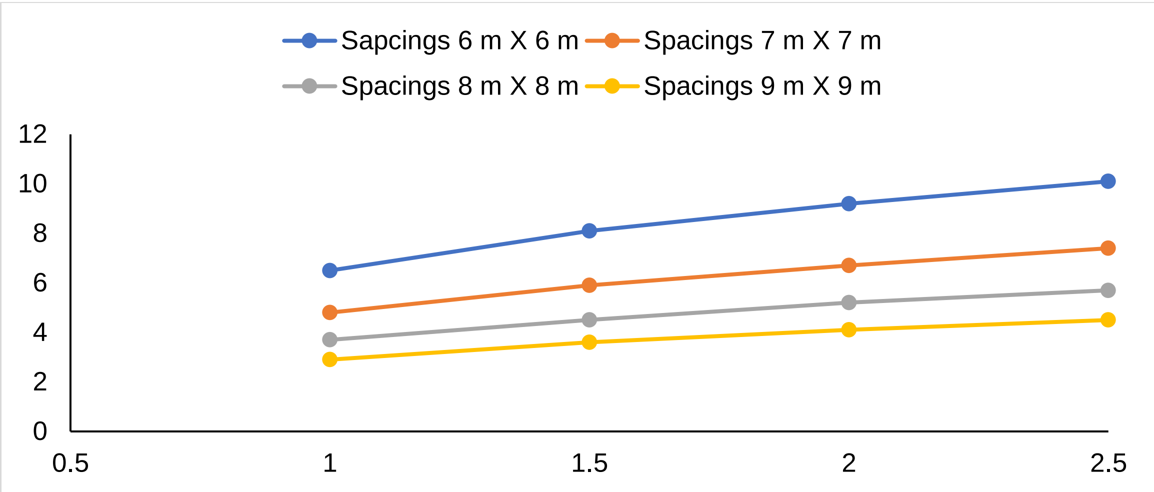

Fig. 7. Application rate at various operating pressures

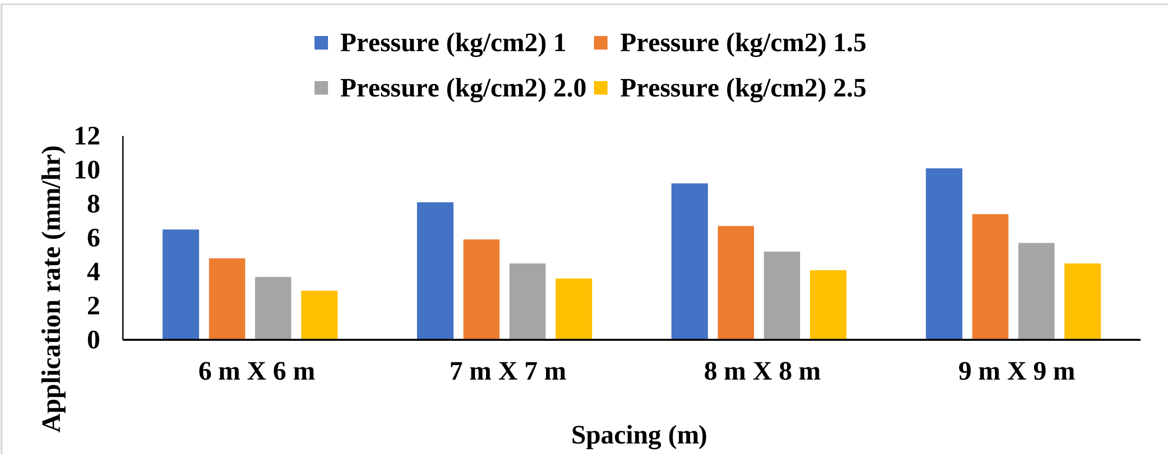

Fig. 8. Application rate at various sprinkler spacing's

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

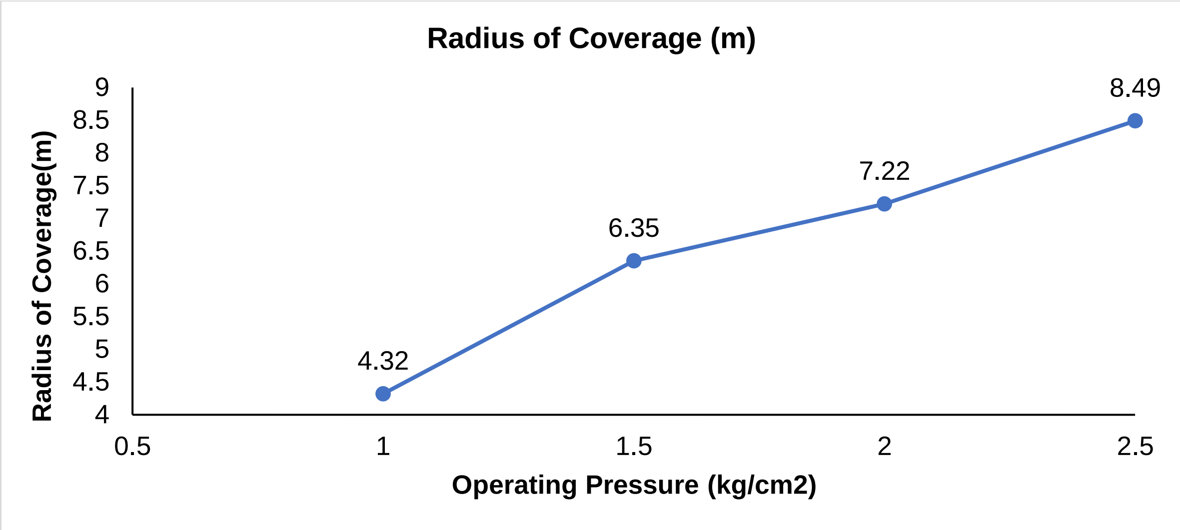

Fig. 9. Radius of coverage of mini sprinkler at various operating pressures

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 /cm^{2}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.

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/cm^2 and least application rate is obtained at 7 m x 7 m spacing and operating pressure of 1.5 kg/cm^2. It will be necessary to raise the operating pressure in order to achieve better application rates at greater spacings. Lowering the pressure results in a significant change in the application rate. To achieve better application rates, it is recommended to maintain the spacing as low as possible if low operating pressure is available. For instance, even with a modest working pressure of 1 kg/cm2, the application rate at a spacing of 6 m x 6 m is 6.5 mm/h. When the working pressure was kept at 2.5 kg/cm2, an application rate of 7.4 mm/h was achieved even at 7 m x 7 m spacing.

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.

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/cm^2 and maximum radius of coverage is obtained when the mini sprinkler is operated at the pressure of 2.5 kg /cm^2. The difference between the maximum and minimum radius of coverage is 4.32 metres. At the pressure of 2.0 kg/cm^2, 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 indicated in the Fig. 9, the smallest area of coverage was acquired when the mini sprinkler was run at 1.5 kg/cm2, while the largest area of coverage was obtained when the tiny sprinkler was operated at 2.5 kg/cm2. The maximum and minimum coverage areas differ by 58.60 square metres. At a pressure of 2.0 kg/cm2, the area covered is 163.76 square meters.

4. CONCLUSIONS

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. 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. 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 mx 6 m arrangement operating at a pressure of 1.5 kg/cm². 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. Effective radius of thow 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. 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. Mean application rate was in the range of 4.5 mm/h to 6.5 mm/h.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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