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Xing Xu,[1] Hongya Ma,[1] Yun Zhao,[1] Xiaoshu Lv[2,3]

Zawar Hussain[1,2], Junping Liu[1*], Junaid Nawaz Chauhdary[1,3], Yanyan Zhao[1], Yuebin Wang[1]

[1]Research Centre of Fluid Machinery Engineering and Technology, Jiangsu University, Zhenjiang, China
[2]Department of Agricultural Engineering, Bahauddin Zakariya University, Multan, Pakistan
[3]Water Management Research Centre, University of Agriculture, Faisalabad, Pakistan

Corresponding author: Yun Zhao, School of Information and Electronic Engineering, Zhejiang University of Science and Technology, Hangzhou, China. E-mail: zy_super0201@163.com

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Zawar Hussain[1,2], Junping Liu[1*], Junaid Nawaz Chauhdary[1,3], Yanyan Zhao[1], Yuebin Wang[1]

[1]Research Centre of Fluid Machinery Engineering and Technology, Jiangsu University, Zhenjiang, China
[2]Department of Agricultural Engineering, Bahauddin Zakariya University, Multan, Pakistan
[3]Water Management Research Centre, University of Agriculture, Faisalabad, Pakistan

Corresponding author: Junping Liu**,** Research Centre of Fluid Machinery Engineering and Technology, Jiangsu University, Zhenjiang 212013, China. E-mail: liujunping401@163.com

Abstract

The current study was design to evaluate the performance of rotating spray plate sprinklers, R3000 with three nozzle sizes i.e., #16-N1, #24-N2 and #32-N3 corresponding to 3.18, 4.76 and 6.35 mm diameters, respectively using various combinations of operating pressure, OP (P1:100 kPa; P2:150 kPa; P3:200 kPa; P4:250 kPa), sprinkler spacing (4-8 m) and sprinkler mounting height, SMH (H1:100 cm; H2:150 cm). The performance of sprinkler nozzles regarding water distribution pattern was examined using wetted radius, Christiansen's uniformity coefficient (CU) and distribution uniformity (DU). The data collection regarding water distribution from selected nozzles was performed using catch cans, placed at 1 m^2 grids. The results revealed that the wetted radius of all selected nozzles increased by increasing the OP and SMH and the maximum values of the wetted radius of N1, N2 and N3 were 7.12, 8.26 and 8.68 m, respectively, under P4 and H2. Moreover, the combined effect of P4 and H2 produced the highest values of CU and DU for each nozzle i.e., CU:86.95%; DU:82.05% for N1 at 6 m spacing, CU:89.21%; DU:83.20% for N2 at 7 m spacing, and CU:86.44%; DU:80.36% for N3 at 7 m spacing. It was found that the wetted radius, CU and DU of R3000 sprinklers for selected nozzles increased by increasing the OP and SMH within the selected range of pressures and heights.

Keywords: Christensen's uniformity coefficient, distribution uniformity, rotating spray plate sprinkler, water distribution pattern, wetted radius.

Introduction

Sprinkler irrigation systems are frequently employed, particularly in the regions with unfavorable terrain topography for conventional irrigation. The initial investment in a sprinkler irrigation system is high compared to other traditional irrigation systems; nevertheless, the sprinkler irrigation system is very adaptable and can significantly improve the crop water use efficiency (Chauhdary *et al.,* 2023; Montazar and Sadeghi, 2008; Zhu *et al.,* 2018). Sprinkler irrigation has the potential to significantly advance the irrigation development in developing countries if the technology is correctly selected, planned, and implemented. The development of the sprinkler irrigation system has been accelerated and modernized by irrigated agriculture in many parts of the world (Kulkarni, 2011; Zhu *et al.,* 2018). To improve the irrigation processes from a technical, organizational, and financial perspective, a wide range of solutions have been applied during the period of sprinkler irrigation technology development (Chen *et al.,* 2022; Hua *et al.,* 2022; Liu *et al.,* 2016). The innovative irrigation developments all over the world employ center-pivot and lateral move irrigation systems commonly due to their advantages over other irrigation systems. To mitigate wind drift, evaporation losses, and energy cost, these continuous move sprinkler systems employ low-pressure spray plate sprinklers rather than high-pressure impact sprinklers (Li *et al.*, 2019; Singh *et al.*, 2010; Tarjuelo *et al.*, 2015). Fixed spray plate sprinklers (FSPSs) were the first type of low-pressure spray plate sprinklers. Recently, new developments in this field have made it possible for rotating spray plate sprinklers (RSPSs) to hit the market. The RSPSs are being used in sprinkler irrigation machines successfully.

The rotating spray plate sprinkler has a rotating plate having the grooves on it and the rotating plate rotates under the pressure of the water jet. These grooved plates come in different types with different droplet size distributions and water application rates. The application uniformity is considered as the key performance criterion to design and evaluate the sprinklers (Tang *et al.,* 2018). The operating pressure, sprinkler nozzle size and the sprinkler spacing influence the sprinkler application uniformity (Kincaid, 1996). The uniformity of the sprinkler can be assessed by statistical performance indicators to determine the overall performance of sprinkler discharge. That ultimately affects the agricultural productivity of a sprinkler system (Keller and Bliesner, 1990; Wilson and Zoldoske, 1997).

Christiansen's Uniformity Coefficient (CU) is commonly used worldwide as a measure of water distribution uniformity and there must be a Christiansen's uniformity coefficient of more than 84%.

It is recommended that arrangements that produce results below this threshold be avoided (Keller and Bliesner, 1990). The distribution uniformity (DU) is another performance indicator that expresses the application uniformity of an irrigation system (Dwivedi and Pandya, 2016). In general, a Distribution Uniformity (DU) of less than 70% is considered poor, between 70% and 90% is considered as good, and above 90% is rated as excellent (Mohamed *et al.*, 2019). The uniformity of the sprinkler irrigation system is affected by the nozzle characteristics and water distribution methods. The key function of the sprinkler nozzle is to distribution the water evenly without producing surface runoff and excessive root zone drainage (Kara *et al.*, 2008). Therefore, the nozzle is considered as the key element in the sprinkler irrigation system. Ahaneku (2010) performed the catch can test to evaluate the performance of sprinkler system and found that the Christiansen's uniformity coefficient and delivery performance ratio were 86% and 87%, respectively. Dwivedi and Pandya (2016) conducted a study by arranging the sprinklers at four different sprinkler spacings and four different working pressures. the findings indicated that the uniformity coefficient was in the range of 72.8% to 89.2%. Liu *et al.* (2018) conducted a study to access the performance of RSPSs. Their investigation focused on three different nozzle diameters, all tested at an elevation of 1.2 meters and examined the sprinklers' performance across a range of operating pressures, varying from 100 to 300 kPa, to assess how these factors influenced the hydraulic performance. Based on the results, it was concluded that the operating pressure had no effect on discharge coefficient, but discharge coefficient was dependent on nozzle size, and wetted radius was dependent on working pressure as well as nozzle size. A study conducted by Darko *et al*. (2018) developed empirical equations for water distribution from fixed spray plate sprinklers (FSPSs) using a linearly moved irrigation system (LIMS) and found that the uniformity of the irrigation system was influenced by the following factors; the distance from the sprinkler, the rise height, and the working pressure of the irrigation system. Chen *et al.* (2020) studied the effect of nozzle size and operation pressure on the spray characteristics of low-pressure spray plate sprinklers and recommended that larger nozzle should be operated under low operating pressure.

It is cleared from the above discussion that research on the sprinkler systems has predominantly focused on evaluating their performance on the basis of one or two of the following parameters: operating pressure, spray plate type, nozzle size, nozzle type riser height and spacing between the sprinklers etc. But this study evaluates the performance of the RSPSs on the basis of three operating parameters i.e., operating pressure (OP), sprinkler mounting height (SMH) and spacing between the sprinklers (SS); in light of the widespread use of RSPSs in center-pivot and lateral-move irrigation systems. The objectives of current study were to obtain the optimum combination of OP, SMH and SS for three nozzle sizes of rotating spray plate sprinklers using linearly moved irrigation system. Christiansen's uniformity coefficient (CU), distribution uniformity (DU), water distribution pattern (WDP) and wetted radius (WR) were calculated to find the best combination of OP, SMH, and SS for selected nozzle sizes.

Materials and Methods

Experimental setup

The Experimental work was conducted in the irrigation laboratory of Jiangsu University at the Research Centre of Fluid Machinery Engineering and Technology, Zhenjiang city, Jiangsu province, China. Performing the experiments in indoor laboratory ensures the radial distribution of water and reduces the WDEL (wind drift and evaporation losses) (Liu *et al.*, 2013; Zhu *et al.*, 2012). The prototype of linearly moved irrigation system developed by the Research Centre of Fluid Machinery Engineering and Technology, Jiangsu University was used as a test bench to perform the experiments. The span length of this system was 12 meters. Four different operating pressures (OPs) and two sprinkler mounting heights (SMHs) were selected to find the effect of pressure and height on the wetted radius (WR), Christiansen's uniformity coefficient (CU), distribution uniformity (DU) and water distribution pattern (WDP) of R3000, RSPSs manufactured by Nelson Irrigation Corporation, Walla, Washington, USA (Figure 1). The R3000 sprinklers with a set of three nozzles numbered 16, 24 and 32 corresponding to 3.18, 4.76 and S6.35 mm nozzle diameters (dia.) respectively, were selected for this study. Table 1 presents the configuration parameters of the selected sprinkler.

Figure 1. Rotating spray plate sprinkler, R3000.

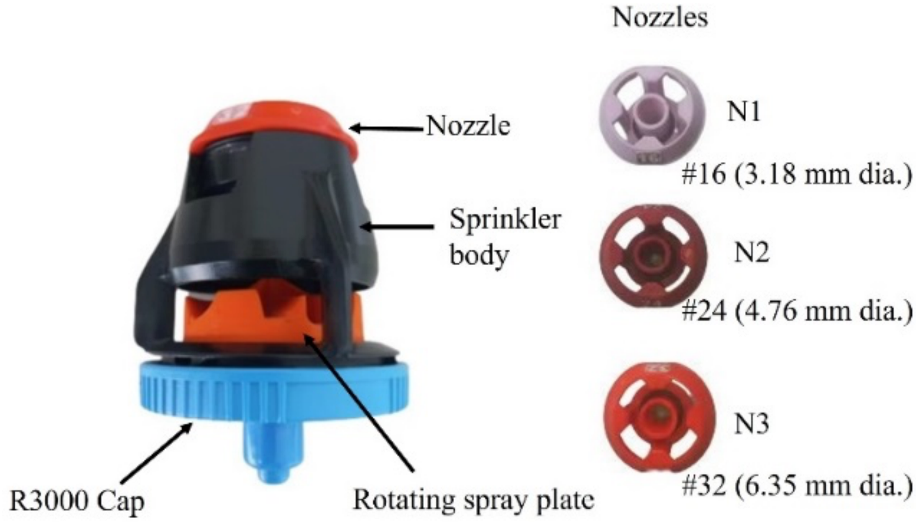
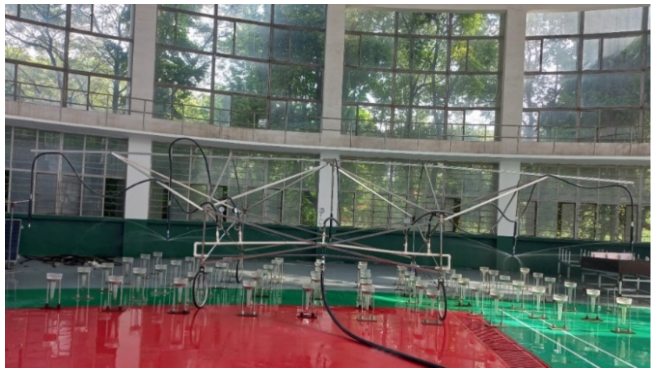


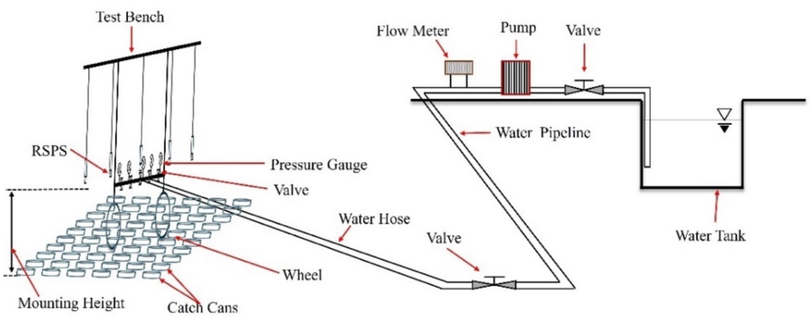
Table 1. Rotating spray plate sprinklers' configuration parameters.

Type of sprinkler	Type of rotating spray plate	Mounting height of sprinkler in cm	Nozzle diameter in mm	Number of grooves on rotating spray plate
R3000, RSPS	Multi-trajectory Orange plate 	100 150	3.18 4.76 6.35	8

Liu *et al.* (2018) reported that RSPSs of 3000 series may be operated under pressures ranging from 70 to 350 kPa. Therefore, four OPs P1, P2, P3 and P4 corresponding to 100, 150, 200 and 250 kPa respectively and two SMHs H1 and H2 corresponding to 100 and 150 cm respectively were selected for the performance evaluation of R3000 sprinklers. The selected OPs were within the range of pressures, recommended by the manufacturer and covered the range of the OPs that are being used in the field, moreover the SMHs were also within the range of heights usually used for low pressure spray plate sprinklers (Ahmed *et al.,* 2010; Opoku *et al.,* 2018; Cai *et al.,* 2020; Hussain et al., 2024). In these experiments, the system was set in the stationary position to spray water over the catch cans at four different operating pressures, two different mounting heights and three different spacings for each nozzle diameters. However, if allowed, the system can move in a linear or straight path that can cover the entire width to work and irrigate the field in one pass. The water supply method involves the use of a flexible "drag hose" attached to the piping system. The sprinkler spacings for nozzle N1 were 4, 5 and 6 m, for N2 were 5, 6 and 7 m, and for N3 were 6, 7 and 8 m. the sprinkler spacings were selected on the basis of the wetted radius of the respective nozzles. According to Topak *et al.* (2004) sprinkler irrigation evaluation is usually based on the coefficients of uniformity collected in the catch can experiment. Thus, the water application data was collected by performing the catch can test. The water application data was collected using plastic catch cans with an inner diameter of 20 cm and a height of 45 cm. A total of 60 catch cans were used to perform the catch can test. The catch cans were arranged at uniform spacing of 1 m x 1 m to form a grid of 6 rows and 10 columns of catch cans at the area under the sprinklers. The experimental setup design was in accordance with the experimental design of (Darko *et al.*, 2019), who conducted the uniformity test for spray tube irrigation system. Figure 2 shows the experimental set up for the current study.



(a)



(b)

Figure 2. Experimental setup; (a) Pictorial view (b) schematic diagram.

However, the data of the inner 8 columns and 4 rows of catch cans were computed in the data analysis because the outermost rows and columns of catch cans did not come under the overlapped area. Therefore, the water application data of catch cans at position 1 to 32 (shown in Figure 3) in experimental layout were analyzed to determine the CU, WDP, WR, and DU. These numbers show the catch cans positions under the sprinkler system. Three sprinkler heads with nozzles N1 and N2, and two sprinkler heads with nozzle N3 were used to find the optimum combination of operating pressure, sprinkler spacing and mounting height for each nozzle size.

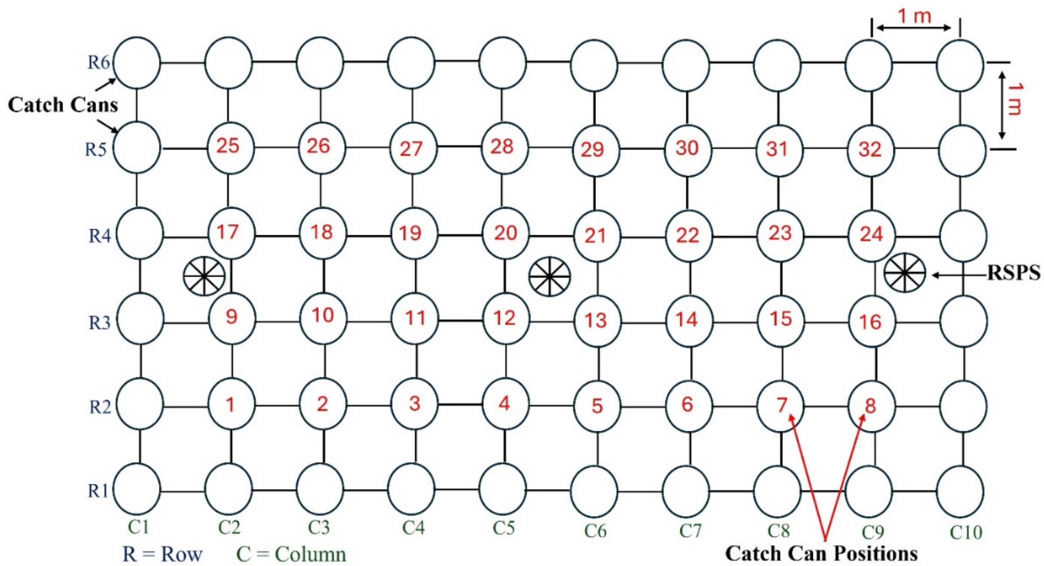


Figure 3. Experimental layout showing the catch cans positions.

Procedure

The three sprinkler heads (R3000) with nozzle N1 were arranged at 4 m sprinkler spacing (SS) in LMIS at H1. After accomplishing the necessary adjustments of sprinkler irrigation system, the pumping unit was switched on and the pressure value for each sprinkler was set at 100 kPa. The sprinkler system was operated to distribute water over the catch cans for a duration of 10 minutes. Then the water supply valve was closed, and the water depths captured in catch cans were recorded. The water depth captured in numbered catch cans from catch can number 1 to 32 (shown in Figure 3) was analyzed to find the CU, DU and WDP. The WR was also measured by considering the wetted area by the sprinkler. Three replications of this experiment were carried out to perform analysis of variance (ANOVA) and least significant difference (LSD) and the mean values of the above-mentioned parameters were determined for 4 m spacing. Then, the operating pressure was changed to 150 to 250 kPa with 50 kPa increment for the same setting of the sprinkler system and the experiments were conducted for required parameters. For this nozzle diameter the same procedure was adopted to perform the experiments at 5 m and 6 m spacings as well as at mounting height H2. After performing the experiments for nozzle N1 the experiments for other nozzles i.e., N2 and N3 were performed at their respective sprinkler spacings by adopting the above procedure. Then, the effect of the operating pressures (OPs) and sprinkler mounting heights

(SMHs) on the CU, DU, WR, WDP were determined to find the optimal combination of OP, SMH and SS for each nozzle size.

Data analysis

Wetted radius

The wetted radius (WR) is an important parameter of the sprinkler head because it determines the wetted area, average application rate, and runoff potential. There is an approximately direct relationship between the wetted area and the wetted radius of the sprinkler. From an economic point of view, the allowable maximum sprinkler spacing to obtain satisfactory uniformity is determined by wetted radius and the sprinkler spacings determine the equipment and labor costs (Liu *et al.*, 2018). The measuring tape was used to measure the wetted radius of the sprinkler.

Christiansen's uniformity coefficient

Christiansen's uniformity coefficient (CU) is an important parameter in designing sprinkler irrigation systems and one of the most crucial parameters to measure the quality of sprinkler irrigation. Christiansen first proposed the following equation (Eq.1) for the uniformity coefficient to describe the uniformity of sprinkler irrigation water distribution quantitatively (Christiansen, 1942) and it has been widely used in different countries worldwide (Ahmed et al., 2010; Cai et al., 2020; Jiao et al., 2017).

$$CU = \left(1 - \frac{\sum_{i=1}^{n}|h_i - \bar{h}|}{\sum_{i=1}^{n} h_i}\right) \times 100 \qquad \text{Eq. 1}$$

$$\bar{h} = \sum_{i=1}^{n} \frac{h_i}{n} \qquad \text{Eq. 2}$$

Where CU is Christiansen's coefficient of uniformity; h_i is the water depth of the ith catch can (mm); $\bar{h}$ is the average water depth collected in catch cans (mm); *n* is the total number of catch cans.

Distribution uniformity

The distribution uniformity (DU) measures how uniformly water is applied to the area being irrigated and is expressed in percentage. DU indicates the water application uniformity throughout the field. The distribution uniformity was proposed by (Merriam and Keller, 1978) and was calculated by dividing the average low quarter depth of application to the overall average depth of application expressed as percentage.

$$DU = \frac{Average\ low\ quarter\ depth\ of\ application}{overall\ average\ depth\ of\ application} \times 100 \qquad \text{Eq. 3}$$

Statistical analysis

The statistical package for social sciences (SPSS) data analysis software was use to analyze the data and to perform the ANOVA (analysis of variance to determine the significant effect of OP on WR, CU, DU for R3000 sprinkler with three nozzles at different spacings and heights. The one-way ANOVA was performed by taking OP as a factor and WR, DU, CU as response variables for the selected nozzles at different spacings and heights. After performing the ANOVA, the least significant difference (LSD) test was performed to check the significant difference between the mean within the groups.

Results

Wetted radius

The wetted radius for the selected nozzles was measured at four operating pressures and two sprinkler heights. The wetted radius increased by increasing the nozzle diameter at the same working pressure. For example, the values of wetted radius for nozzle N1, N2 and N3 were 5.73, 6.84, and 7.25 m, respectively, at pressure P1 and height H1. Approximately the same trend was observed at P2, P3, and P4. As it can be seen in Figure 4, the wetted radius increased by increasing the operating pressures for the same nozzle size. For example, the wetted radius of nozzle N1 under P1, P2, P3, and P4, and sprinkler height H2 was 6.50, 6.82, 6.97 and 7.12 m respectively. The increasing trend in the wetted radius of other two nozzles at different operating pressures was also observed as it can be seen in Table 2 and Figure 4.

Table 2. Effect of selected operating parameters on the wetted radius in meters.

Operating pressure	Nozzle N1 (3.18 mm diameter)		Nozzle N2 (4.76 mm diameter)		Nozzle N3 (6.38 mm diameter)	
	Sprinkler mounting height		Sprinkler mounting height		Sprinkler mounting height	
	H1	H2	H1	H2	H1	H2
P1	5.73c	6.50c	6.84c	7.24c	7.25c	7.70c
P2	6.39b	6.82b	7.45b	7.85b	7.75b	8.25b
P3	6.59ab	6.97ab	7.72a	8.12a	8.00a	8.50a
P4	6.82a	7.12a	7.91a	8.26a	8.20a	8.68a
	LSD at H1 = 0.23	LSD at H2 = 0.21	LSD at H1 = 0.25	LSD at H2 = 0.18	LSD at H1 = 0.22	LSD at H2 = 0.19

[a,b,c]no significant difference according to ANOVA ($p<0.05$) and LSD test; P1, P2, P3 and P4 correspond to 100, 150, 200 and 250 kPa, respectively; H1 and H2 correspond to 100 and 150 cm, respectively.

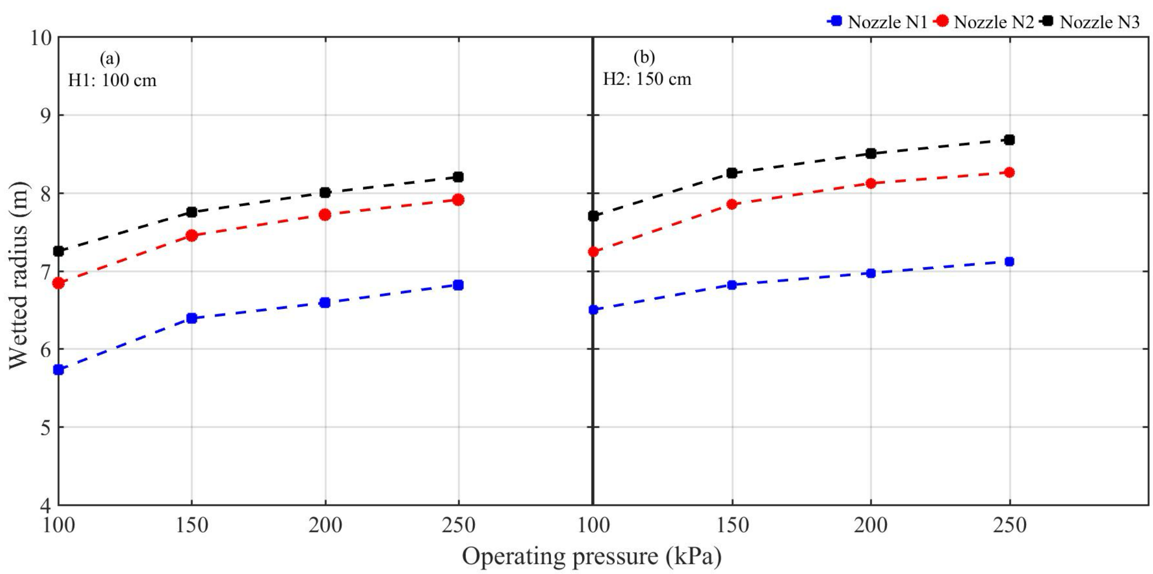


Figure 4. Effect of operating pressure (OP) on wetted radius at different mounting heights; H1 and H2: *(Nozzle N1:3.18 mm dia.; Nozzle N2:4.76 mm dia.; Nozzle N3:6.35 mm dia.)*

Meanwhile, the effect of SMH on the wetted radius for all selected nozzles was checked and found that the wetted radius for the same nozzle size and under the same OP increased by increasing the SMH. For example, the approximate values of the wetted radius for nozzle N1 under pressure P1 and at H1 and H2 were found to be 5.73 m and 6.50 m, respectively. The increasing trend in the wetted radius of other nozzles under the same operating pressure was also observed by increasing the SMH, as it can be seen in Table 2 and Figure 5.

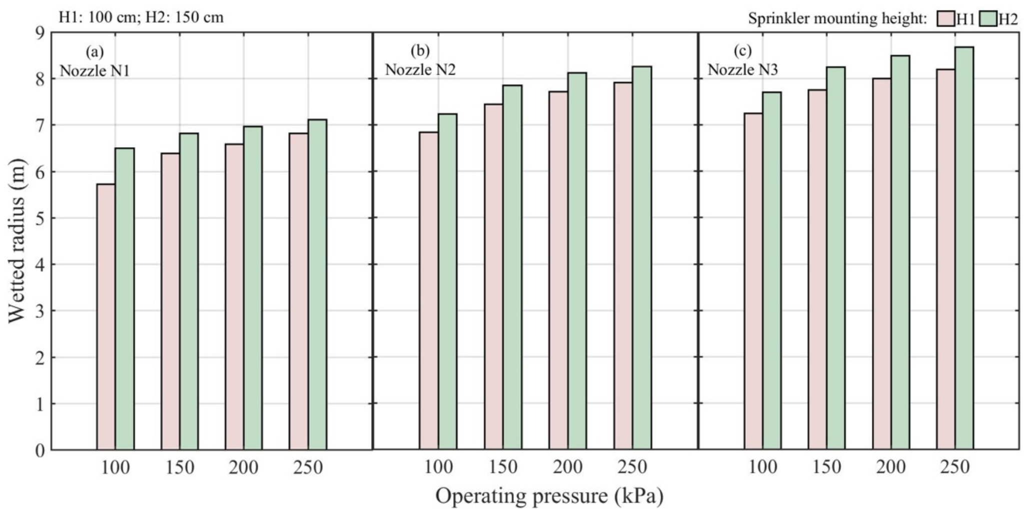


Figure 5. Effect of sprinkler mounting height (SMH) on wetted radius of selected nozzles at different operating pressures.

CU of sprinkler R3000 with different nozzles

The Christiansen's uniformity coefficient (CU) of RSPS, R3000 with three nozzle sizes having the diameters of 3.18, 4.76 and 6.35 mm for three different SS for each nozzle size and at two SMHs were calculated to find the effect of OP and SMH on the uniformity. Figure 6 shows the effect of OP on the CU for selected nozzles at different sprinkler spacings and heights. The CU of R3000 sprinkler with nozzle diameters tested increased by increasing the OP for all selected spacings and heights. Taking nozzle N1 as an example, the CU values under P1, P2, P3, and P4 were 80.69%, 83.85%, 85.50%, and 86.95% respectively at 6 m spacing and at height H2. The increasing trend in CU by increasing the operating pressure was also found at 4 m and 5 m spacings at H1 and H2 as well. The maximum values of the CU of R3000 sprinkler with nozzle N1 under pressure P4 and at 6 m sprinkler spacing were found to be 83.06% and 86.95% at H1 and H2, respectively (can be seen in Table 3). In case of R3000 with Nozzle N2, the CU values under P1, P2, P3, and P4 were 81.57%, 86.51%, 87.40%, and 89.21% respectively at 7 m spacing and at height H2. The increasing trend by increasing the OP was also found at 5 m and 6 m spacing for both SMHs as well. The maximum values of the CU of R3000 sprinkler with Nozzle N2 under P4 and at 7 m sprinkler spacing were found to be 84.59% and 89.21% at H1 and H2, respectively (can be seen in Table 3). In case of R3000 sprinkler with Nozzle 3, the CU values at P1, P2, P3, and P4 were 79.13%, 81.48%, 84.59%, and 86.44%, respectively at 7 m spacing and H2. The increasing trend with the increase in OP was found at 6 m and 8 m spacing for both SMHs as well. The maximum values of the CU of R3000 sprinkler with Nozzle N3 under P4 and at 7 m sprinkler spacing were found to be 85.68% and 86.44% at H1 and H2, respectively (Table 3).

Table 3. Effect of operating pressure (OP) and sprinkler mounting height (SMH) on Christiansen's uniformity coefficient CU (%).

Nozzle size	Operating pressure	Sprinkler mounting height					
		4 m spacing		5 m spacing		6 m spacing	
		H1	H2	H1	H2	H1	H2
N1: 16/128 in. (3.18 mm)	P1	74.48b	78.08d	71.92d	77.86c	74.49c	80.69d
	P2	75.51ab	81.82c	73.44c	79.69b	78.94b	83.85c
	P3	75.87a	84.43b	74.79b	81.04b	79.70b	85.50b
	P4	76.05a	85.42a	76.26a	83.39a	83.06a	86.95a
		LSD at H1 = 1.31	LSD at H2 = 0.48	LSD at H1 = 0.75	LSD at H2 = 1.50	LSD at H1 = 0.93	LSD at H2 = 0.53
		5 m spacing		6 m spacing		7 m spacing	
N2: 24/128 in. (4.76 mm)	P1	68.27d	70.16d	70.74d	72.90d	70.31d	81.57d
	P2	70.18c	75.91c	72.21c	80.21c	76.07c	86.51c
	P3	72.91b	79.63b	74.45b	82.67b	80.99b	87.40b
	P4	74.52a	82.03a	76.80a	83.32a	84.59a	89.21a
		LSD at H1 = 1.20	LSD at H2 = 0.30	LSD at H1 = 0.83	LSD at H2 = 0.54	LSD at H1 = 1.10	LSD at H2 = 0.85
		6 m spacing		7 m spacing		8 m spacing	
N3: 32/128 in. (6.35 mm)	P1	70.37c	77.46d	72.16d	79.13d	67.02d	71.08d
	P2	74.19b	79.17c	76.63c	81.48c	68.59c	76.33c
	P3	75.44b	80.26b	81.88b	84.59b	71.99b	77.78b
	P4	79.90a	82.43a	85.68a	86.44a	76.32a	79.10a
		LSD at H1 = 1.30	LSD at H2 = 0.49	LSD at H1 = 0.38	LSD at H2 = 1.18	LSD at H1 = 0.41	LSD at H2 = 0.50

[a,b,c]no significant difference according to ANOVA (p<0.05) and LSD test; P1, P2, P3 and P4 correspond to 100, 150, 200 and 250 kPa, respectively; H1 and H2 correspond to 100 and 150 cm, respectively.

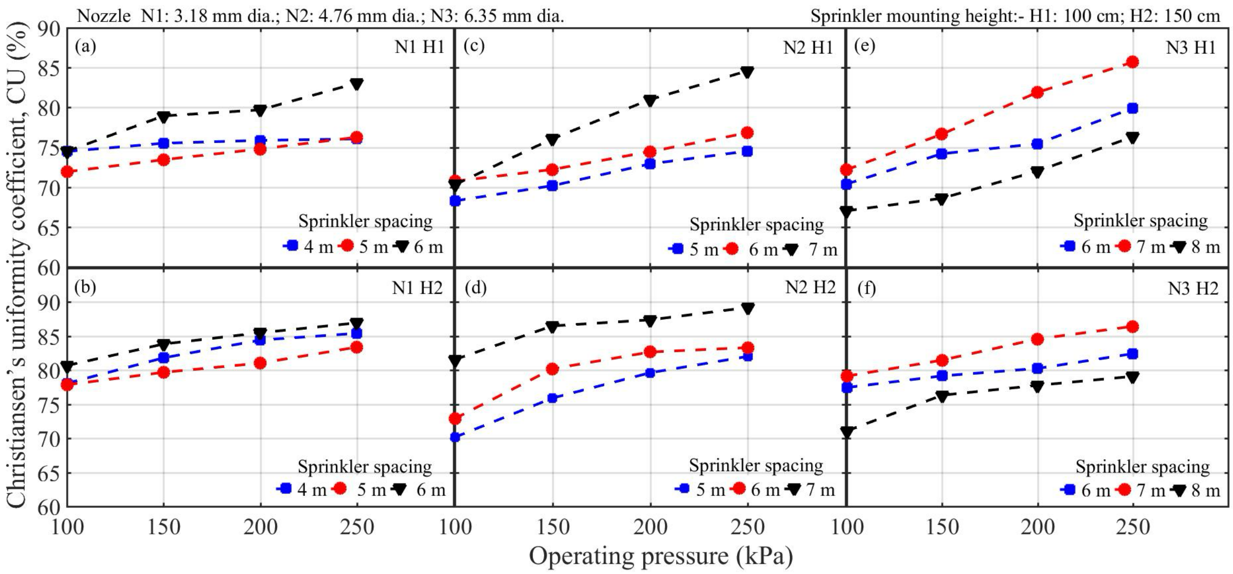


Figure 6. Effect of operating pressure (OP) on the Christiansen's uniformity coefficient of R3000 sprinkler with different nozzles at different spacings and heights.

Meanwhile, the effect of SMHs on CU for all selected sprinkler nozzles was also determined in this study and it was found that CU for each SS and OP increased by increasing the SMH, as can be seen in Figure 7. From the experimental results, it is clear that the maximum CU values were obtained when the sprinklers were operated at higher pressure and set at higher mounting height. There was a direct proportionality between CU and the combined effect of OP and SMH. The effect of OP and SMH on the CU of selected nozzles at different SS can be seen in Table 3.

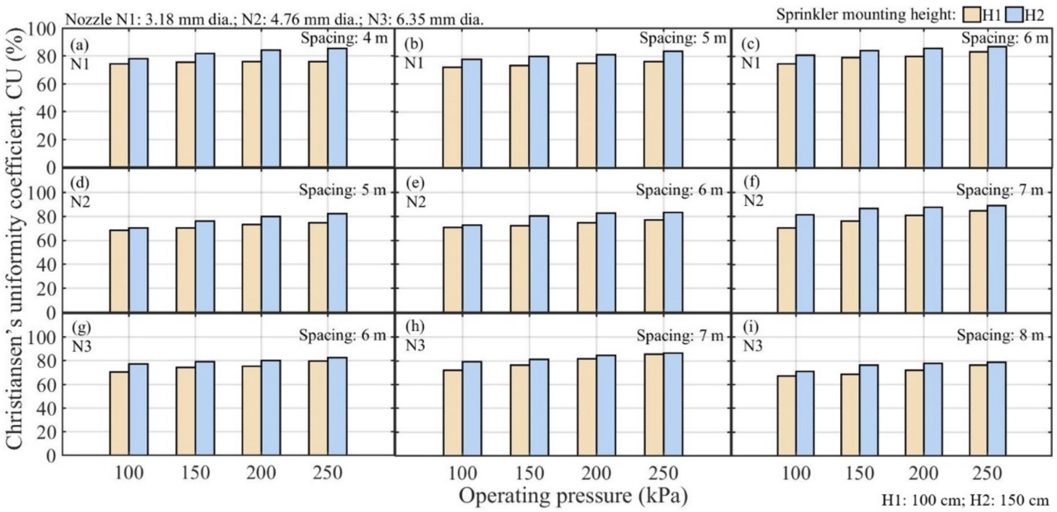


Figure 7. Effect of sprinkler mounting height (SMH) on the Christiansen's uniformity coefficient of R3000 sprinkler with different nozzles at different pressures and spacings.

DU of sprinkler R3000 with different nozzles

The Distribution uniformity (DU) of RSPS, R3000 with three nozzle sizes having the diameters of 3.18, 4.76 and 6.35 mm for three different spacings for each nozzle size and at two heights were calculated to find the effect of operating pressures and sprinkler mounting heights on uniformity. Figures 8 shows the effect of OP on the DU of selected nozzles at different sprinkler spacings and heights. The DU of R3000 sprinkler with nozzle diameters tested increased by increasing the OP for all selected SSs and SMHs. Taking nozzle N1 as an example, the DU of R3000 sprinkler at 6m sprinkler spacing and at height H2 were 69.16%, 74.67%, 76.87%, and 82.05% (can be seen in Table 4) under P1, P2, P3 and P4 respectively. The increasing trend in DU by increasing the OP was also found at 4 m and 5 m spacings for both SMHs as well. The maximum values of DU for nozzle N1 under pressure P4 and at 6 m sprinkler spacing were found to be 73.05% and 82.05% at H1 and H2, respectively. In case of sprinkler with nozzle N2, the DU values at 7 m sprinkler spacing and at H2 were 71.88%, 77.09%, 79.89%, and 83.20% under P1, P2, P3 and P4 respectively (shown in Table 4). The increasing trend in DU by increasing the OP was also found at 6 m and 7 m sprinkler spacings for both SMHs as well. The maximum values of DU for nozzle N2 under pressure P4 and at 7 m sprinkler spacing at height H1 and H2 were 81.53% and 83.20%, respectively. In case of sprinkler with nozzle N3, the DU values at 7 m sprinkler spacing and at H2 were 74.84%, 77.27%, 78.87%, and 80.36% under P1, P2, P3 and P4 respectively (can be seen in Table 4). The increasing trend in DU by increasing the operating pressure was also found at 7 m and 8 m spacings for both mounting heights as well. The maximum values of DU for nozzle N3 at H1 and H2 were 73.59% and 80.36% respectively at pressure P4 and at 7 m sprinkler spacing.

Table 4. Effect of operating pressure (OP) and sprinkler mounting height (SMH) on distribution uniformity DU (%).

Nozzle size	Operating pressure	Sprinkler mounting height					
		4 m spacing		5 m spacing		6 m spacing	
		H1	H2	H1	H2	H1	H2
N1: 16/128 in. (3.18 mm)	P1	62.75c	69.02d	60.03d	68.92d	61.28d	69.16d
	P2	66.67b	71.25c	61.22c	70.98c	68.48c	74.67c
	P3	67.77ab	76.61b	65.55b	73.99b	71.01b	76.87b
	P4	68.54a	80.38a	67.98a	78.26a	73.05a	82.05a
		LSD at H1 = 1.30	LSD at H2 = 1.49	LSD at H1 =1.15	LSD at H2 = 1.13	LSD at H1 = 1.66	LSD at H2 = 1.73
		5 m Spacing		6 m Spacing		7m Spacing	
N2: 24/128 in. (4.76 mm)	P1	60.95d	63.12d	60.63c	70.37c	66.97d	71.88d
	P2	62.02c	64.56c	61.48c	71.63c	72.92c	77.09c
	P3	64.05b	67.24b	64.18b	74.07b	77.59b	79.89b
	P4	67.45a	73.33a	68.10a	79.33a	81.53a	83.20a
		LSD at H1 = 0.50	LSD at H2 = 0.20	LSD at H1 = 1.30	LSD at H2 = 1.55	LSD at H1 = 0.50	LSD at H2= 0.58
		6 m Spacing		7 m Spacing		8 m Spacing	
N3: 32/128 in. (6.35 mm)	P1	63.89c	68.14d	64.39d	74.84d	60.81d	62.35d
	P2	64.83c	69.80c	65.82c	77.27c	62.59c	66.19c
	P3	66.57b	71.07b	67.15b	78.87b	64.61b	68.02b
	P4	71.81a	72.37a	73.59a	80.36a	66.12a	70.77a
		LSD at H1 = 1.23	LSD at H2 = 0.56	LSD at H1 = 0.55	LSD at H2 = 0.19	LSD at H1 = 0.89	LSD at H2 = 0.39

[a,b,c]no significant difference according to ANOVA ($p<0.05$) and LSD test; P1, P2, P3 and P4 correspond to 100, 150, 200 and 250 kPa, respectively; H1 and H2 correspond to 100 and 150 cm, respectively.

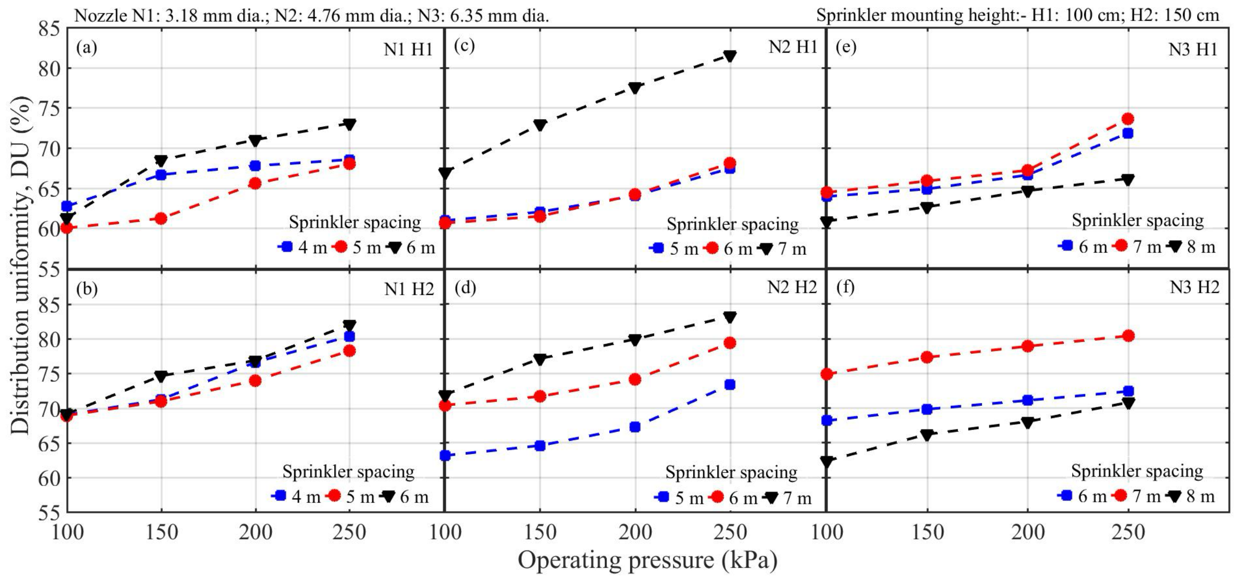


Figure 8. Effect of operating pressure (OP) on the distribution uniformity of R3000 sprinkler with different nozzles at different spacings and heights.

Meanwhile, the effect of SMH on DU for all selected sprinkler nozzles was also determined in this study and it was found that DU for each sprinkler spacing and operating pressure increased by increasing the SMH, as can be seen in Figure 9. From the experimental results, it is clear that the maximum DU values were obtained when the sprinklers were operated at higher pressure and set at higher mounting height. There was a direct proportionality between DU and the combined effect of P and H. The effect of OP and SMH on the distribution uniformity of the selected nozzles at different spacings can be seen in Table 4.

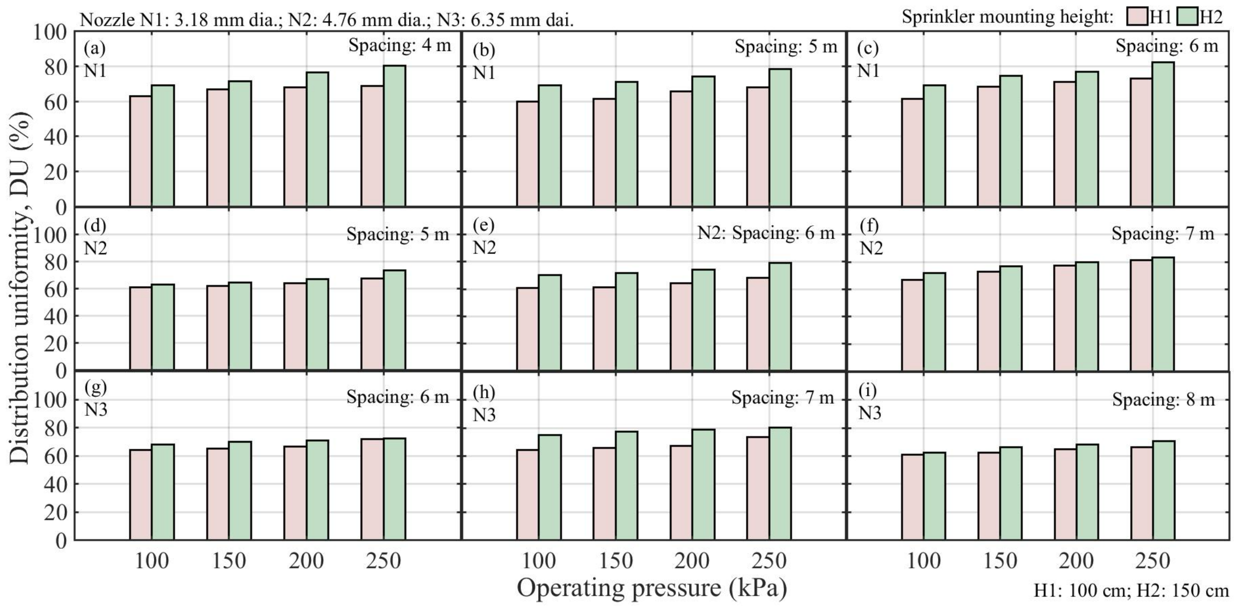


Figure 9. Effect of sprinkler mounting height (SMH) on the Distribution uniformity of R3000 sprinkler with different nozzles at different pressures and spacings.

Water distribution pattern

The water depth captured in the catch cans shows the water distribution pattern. The water depth in catch cans was measured in mm. The water distribution patterns (WDP) for R3000 sprinklers with selected nozzle sizes are shown in Figure 10. Figures 10a, 10b, 10c show the water distribution patter, where 10a shows the WDP for nozzle N1 at selected pressure and spacing range when the sprinklers were installed at height H1 and H2 respectively, 10b shows the WDP for nozzle N2 at selected pressure and spacing range when the sprinklers were installed at height H1 an H2 respectively, 10c shows the WDP for nozzle N3 at selected pressure and spacing range when the sprinklers were installed at height H1 and H2. The mean values of the water collected in catch cans increased with increasing the operating pressure for selected nozzle diameters. For all selected nozzles the water distribution was more uniform at higher operating pressure and mounting height.

As it can be seen in Figure 10 the water distribution curves for nozzle diameters tested were smooth having less peaks when the sprinklers were operated at pressure P4 and installed at height H2. For example, it can be seen in Figure 10a that the water distribution curve was relatively smoother and having the less peaks at pressure P4 as compared to the curves at other pressure settings for nozzle N1, when the sprinklers were installed at height H2 and at 6 m sprinkle spacing. The sprinkler spacing also affected the water distribution pattern. The WDP for nozzles N1, N2 and N3 were comparatively smoother when the sprinkler spacings were 6 m, 7m and 7m respectively.

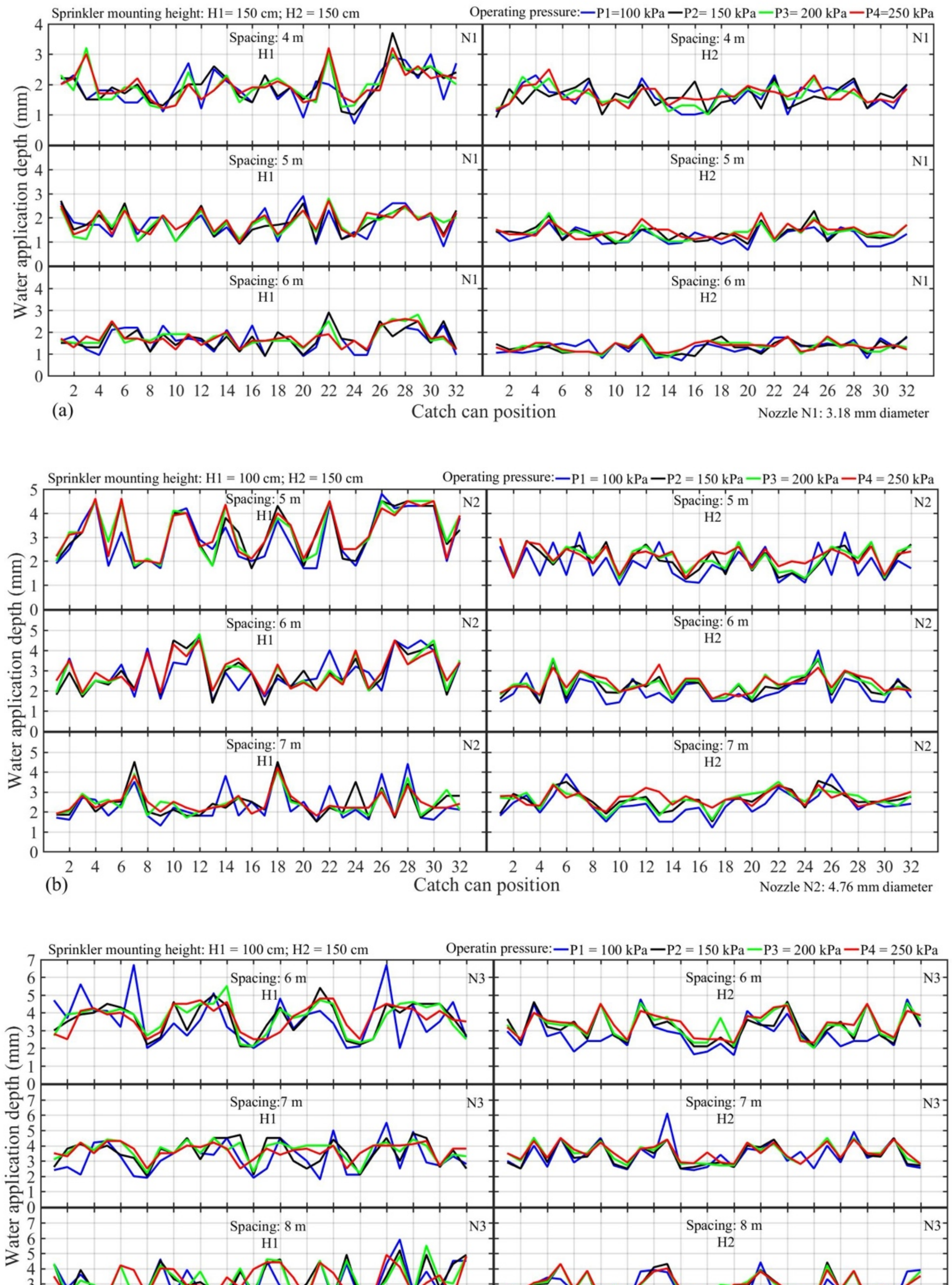


Figure 10. Effect of operating pressures (OP) and sprinkler mounting heights (SMH) on water distribution pattern of R3000 sprinkler with different nozzles: (a) Nozzle N1 (b) Nozzle N2 (c) Nozzle N3.

The operating pressures and sprinkler mounting heights effect on the coefficient of variation (CV) in the values of water depth collected in catch cans was also determined. Table 5 shows the significant influence of OP and SMH on the coefficient of variation (CV). For all nozzle sizes and spacings, the CV values were high at height H1 and pressure P1, which indicated that the degree of non-uniformity was high at P1 and H1. The CV values for all nozzle sizes and spacings decreased by increasing OP and SMH. The minimum values of CV (16.72%) for nozzle N1 at 6 m spacing, CV (13.28%) for nozzle N2 at 7 m sprinkler spacing and CV (15.62%) for nozzle N3 at 7 m spacing were obtained at pressure P4 and height H2. The experimental results showed that when pressure was set from lower to higher, there was a significant difference in CV values.

Table 5. Effect of operating pressures (OP) and sprinkler mounting heights (SMH) on coefficient of variation CV (%).

Nozzle size	Operating pressure	Sprinkler mounting height					
		4 m spacing		5 m spacing		6 m spacing	
		H1	H2	H1	H2	H1	H2
N1: 16/128 in. (3.18 mm)	P1	31.26a	25.30a	33.86a	25.28a	31.63a	23.76a
	P2	28.64b	22.44b	30.78b	23.75b	27.85b	20.28b
	P3	26.48c	19.15c	26.67c	21.29c	24.41c	18.18c
	P4	24.31d	18.27d	24.61d	19.85d	21.71d	16.72d
		LSD at HI = 0.85	LSD at H2 = 0.50	LSD at HI = 0.77	LSD at H2 = 0.49	LSD at HI = 0.95	LSD at H2 = 1.10
		5 m spacing		6 m spacing		7 m spacing	
N2: 24/128 in. (4.76 mm)	P1	36.06a	35.15a	35.22a	32.92a	37.89a	25.40a
	P2	34.26b	27.38b	33.47b	24.92b	31.65b	18.43b
	P3	31.11c	23.98c	30.07c	22.77c	25.66c	15.92c
	P4	29.44d	19.95d	27.32d	19.74d	21.74d	13.38d
		LSD at HI = 1.50	LSD at H2 = 0.48	LSD at HI = 0.98	LSD at H2 = 0.73	LSD at HI = 1.25	LSD at H2 = 1.15
		6 m spacing		7 m spacing		8 m spacing	
N3: 32/128 in. (6.35 mm)	P1	37.18a	30.34a	33.52a	26.04a	36.52a	34.40a
	P2	28.72b	25.99b	26.98b	21.37b	33.86b	29.54b
	P3	25.65c	23.57c	21.94c	17.95c	30.88c	27.06c
	P4	22.50d	20.73d	17.47d	15.62d	26.04d	23.86d
		LSD at HI = 0.63	LSD at H2 = 0.50	LSD at HI = 1.50	LSD at H2 = 1.35	LSD at HI = 1.50	LSD at H2 = 1.25

[a,b,c]no significant difference according to ANOVA ($p<0.05$) and LSD test; P1, P2, P3 and P4 correspond to 100, 150, 200 and 250 kPa, respectively; H1 and H2 correspond to 100 and 150 cm, respectively.

Discussion

The wetted radius of R3000 sprinklers increased by increasing the operating pressure. This is because by increasing the operating pressure the water was discharged persuasively and distributed over a greater distance, resulting in a larger wetted radius. The effect of operating pressure on the wetted radius is in agreement with the findings of other researchers (Chen *et al.*, 2022; Dwivedi and Pandya, 2016). The wetted radius for different nozzle diameters was different at a certain pressure, as the larger nozzle diameter had larger wetted radius. This could be attributed that the nozzle size affects the sprinkler flow rate that ultimately affects the wetted radius. Therefore, the sprinkler with larger nozzle size produced more flow rate that increased the wetted radius. Liu *et al.* (2018) also found that the wetted radius increased with increasing the nozzle diameter at a certain operating pressure. Moreover, at a given pressure and nozzle diameter the wetted radius increased by increasing the SMH. This could be attributed as when the sprinkler is installed at higher elevation then the dispersion of the water droplets is more over the entire wetted area, resulting in a larger wetted radius. In this study it was found that the operating pressure and mounting height influenced the CU, DU and WDP for R3000. Both CU and DU for R3000 sprinklers with selected nozzle diameters increased with increasing operating pressure. This is because at higher operating pressure the water emitted from the sprinklers with more force and rotated the spray plate more evenly, resulting in breaking up the water into fine droplets and the distribution of the water over the area was more uniform. The operating pressure effect on the CU and DU agrees with the finding of other researchers (Kara *et al.,* 2008; Moazed *et al.,* 2010; Dwivedi and Pandya 2016; Darko *et al.,* 2019; Zhang *et al.,* 2013). Moreover, the water distribution by the R3000 sprinklers with selected nozzle diameter was more uniform at higher mounting height for all pressures and spacings. This is because when the sprinklers were installed at higher height the dispersion of water droplets were more before reaching the ground that led toward better uniformity. Therefore, the higher pressure and higher mounting height produced the better uniformity for tested nozzle diameters. The combined effect of higher OP and higher SMH on the water distribution uniformity was in accordance with the findings of (Darko *et al.,* 2018).

Conclusions

The current study was conducted to find the optimum combination of operating pressure, sprinkler mounting height, and spacing for the R3000-RSPSs, with three nozzles diameters 16/128 in. (3.18mm), 24/128 in (4.76mm), and 32/128 in. (6.35mm). From this study, the following conclusions are drawn.

For all tested nozzle diameters, the wetted radius depended on the sprinkler height and working pressure. The wetted radius of all tested nozzles increased by increasing the pressure and height within the selected range of pressure and height. For different nozzles, the maximum value of the wetted radius was obtained under pressure P4 and height H2. The wetted radius was significantly increased at a given pressure by increasing the height. The CV values were minimum for different nozzles under pressure P4 and height H2 i.e., 16.72%, 13.38% 15.62% for nozzle N1, N2 and N3 at 6 m, 7 m and 7 m spacing, respectively. These minimum CV values indicated that the distribution of water over the catch cans was comparatively more uniform under higher pressure P4 and higher mounting height H2. Similarly, The CU and DU for each nozzle size improved by increasing the OP and SMH. The highest values of CU and DU for each nozzle size were found under pressure P4 and height H2 i.e., CU:86.95% and DU:82.05% for N1 at 6 m spacing, CU:89.21% and DU:83.20% for N2 at 7 m spacing, and CU:86.44% and DU:80.36% for N3 at 7 m spacing. By considering the findings of the study, it is suggested that if low pressure is available, the selected nozzles can operate effectively at a low pressure of 100 kPa. As, rotating spray plate sprinkler with tested nozzles are capable of performing well across all selected pressure levels when installed at a height of 150 cm above the ground, with the spacing between sprinklers equals to their wetted radius.

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Data availability statement

The data can be provided by the corresponding author on request**.**

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