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Effect Of Sprinkler Riser Height And Cyclic Pressure Head Variation On Water Distribution Pattern For Grid Sprinkler Irrigation Systems

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ABSTRACT

Operating pressure is one of the most important factors in breaking up and dispersion of the water jet into droplets. In addition, the sprinkler riser helps calm, stabilize, and regulate the flow entering from the lateral pipe. The research aims to determine the effect of the sprinkler riser height and the variation of cyclic pressure head on the water distribution pattern for a single sprinkler and their interaction with the spacing and for rectangular and triangular arrangements of sprinklers. The results showed that the water distribution patterns for a single sprinkler operating under constant pressure head and under a cyclically varying pressure head are similar, and the largest differences didn't show a noticeable change in Christiansen's uniformity coefficient (UC). In addition, increasing riser height resulted in water distribution patterns of lower depths with increase in the wetted radius. Moreover, the largest increase in UC appeared in the triangular arrangement and in the lowest pressure head, and the average increase in UC was 8.65%. It was also noted that increasing the pressure head led to distribution pattern of greater depths near the sprinkler, while the pattern tends to stabilize after that. The overall increase in UC under all variables considered is 1.98%, and 70% of the UC values in the rectangular arrangement are greater than or equal to those in the triangular arrangement.

Keywords:

Riser heights, operational pressure head, irrigation uniformity, grid sprinkler systems, Rectangular and triangular arrangement.

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1. INTRODUCTION

As global water resources face increasing pressure, enhancing the efficiency of agricultural water use is paramount. Sprinkler irrigation systems are a cornerstone of modern agriculture, offering a more controlled application of water compared to traditional surface irrigation methods. The primary objective of achieving good water distribution uniformity is to balance soil moisture and nutrients by preventing water loss due to over-irrigation in some areas of the field and under-irrigation in others. This can lead to crop stress due to water deficit and reduced yield. Several factors affect water distribution uniformity in sprinkler systems, including sprinkler type, nozzle diameter, angle, operating pressure head, spacing and arrangement of sprinklers, riser height, riser deviation from vertical, operating pressure head variation, wind speed, and direction, etc. Each of these parameters can significantly alter the spray pattern and the amount of water delivered to different parts of a field, making their optimization essential for an effective irrigation strategy. The uniform water distribution uniformity is crucial as it provides favorable conditions for growth and production, improves water use efficiency, and becomes even more critical in drought or water scarcity areas, ultimately leading to reduced operational costs for farmers and conservation of a vital natural resource. The relationship between water distribution uniformity and various operating parameters has been the subject of numerous studies. For instance, regarding the operating pressure head, several researchers have shown that water distribution uniformity is better with increasing operating pressure head at the sprinkler nozzle [1], [2], [3], [4], [5]. The range of throw increases with increasing pressure head [5]. With increasing pressure head, the wetting radius at first increases and then decreases after the pressure head reaches a specific value within the range recommended by the manufacturer. The best water distribution uniformity is within certain limits of the operating pressure head recommended by the manufacturer [6], [7] .

Regarding cyclic variation of operating pressure head, the findings are diverse. It is mentioned that an oscillating pressure head (cyclic pressure head variation) has better or equal results when operating at a constant pressure head [8]. To determine the effect of pulsating pressure head (cyclic pressure head variation) on water distribution and water distribution uniformity for sloping land, the researcher in [9] confirmed that the value of Christiansen's uniformity coefficient for spray water distribution at pulsating pressure head is 4.06% higher than the case of constant pressure head, and the researcher recommended using pulsating pressure head in sprinkler irrigation on sloping land to improve the Christiansen's uniformity coefficient of water distribution. In addition, as a result of comparing the values of the Christiansen's uniformity coefficient in the cases of operation with constant pressure head and cyclic varying pressure head at several spacing and for different sprinklers, the researcher in [10] mentioned that 47.5% of these values of the Christiansen's uniformity coefficient in the case of constant pressure head equals the case of cyclic varying pressure head and 22.5% of them in the case of constant pressure head is greater than the case of cyclic varying pressure head and 30% of them in the case of constant pressure head is smaller than in the case of varying pressure head. Examining a rotary sprinkler under a constant pressure head and cyclic varying pressure head showed an increase in irrigation uniformity of up to 6.54% in the case of a cyclic varying pressure head compared to a constant pressure head [11]. The results of laboratory experiments to provide appropriate technical information in the design of a sprinkler system with fluctuating pressure head on sloping land showed that the uniformity of water distribution was better under the gentle slope of the terrain in the triangular arrangement than in the square and rectangular arrangements and that the Christiansen's uniformity coefficient of irrigation water distribution increased with increasing the average pressure head of the fluctuating pressure head, and that the effect of increasing the average fluctuating pressure head on the water distribution uniformity gradually decreases [12]. The results of laboratory tests for four sprinklers under the operating conditions of constant pressure head and cyclic varying pressure head showed that the spray water distribution pattern was identical in the cases of constant and cyclic varying pressure head [13].

Another critical factor is the sprinkler riser height. Several researchers have shown that water distribution uniformity is better with increasing sprinkler riser height[1], [14], [15], [16], [17], [18]. In the case of high wind speed, increasing riser height has a negative effect on water distribution uniformity [17]. Moreover, increasing the riser height leads to an increase in the spray throw and then an increase in the wetted area covered by the sprinkler [19], [20]. An on-site evaluation of the effect of sprinkler riser heights showed an increase in the water distribution uniformity and then a decrease with increasing riser height [21]. The researcher in [22] mentioned that the riser height has a small effect on the distribution pattern in calm winds and indicated that spray losses increase with increasing riser height.

Despite these studies, a review of the literature reveals a gap in the existing research regarding tests to determine the water distribution pattern at two different riser heights from a single sprinkler head operating alone simultaneously to illustrate the effect of riser height. Furthermore, there is a need to investigate the use of two levels of cyclic varying operating pressure head to understand its impact on the water distribution pattern. Therefore, this research aims to determine the effect of riser height and cyclic pressure head variation on the field water distribution pattern for a single sprinkler and its interaction with sprinkler spacing for rectangular and triangular arrangements and for different sprinkler heads. The research includes an introduction, which incorporates the review of previous studies, followed by laboratory tests, and an analysis of the results, followed by their discussion, and concludes with the conclusions.

2. LABORATORY TESTS

To study the effect of sprinkler riser height and cyclic varying operating pressure on water distribution uniformity, it is necessary to obtain water distribution data for each sprinkler individually for four sprinkler types. This involves measuring water depths along a transect representing the radius of the wetted circle at distances equivalent to the spacing of water collection containers in a 2 m × 2 m grid. This is conducted under laboratory conditions to obtain a symmetrical water distribution pattern for a single sprinkler. The experiments were conducted in the Hydraulic Laboratory of the College of Engineering at the University of Mosul. Figure 1

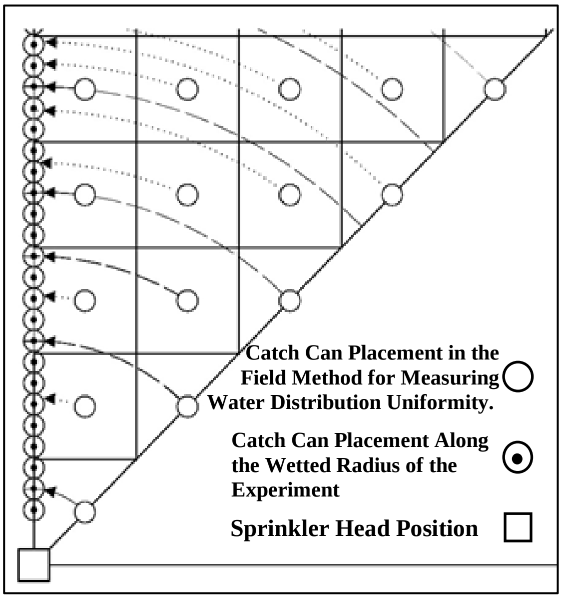


Fig. 1 Water distribution pattern of a single sprinkler resulting along the radius of a wetting circle centered by the sprinkler head.

illustrates the water distribution pattern of a single sprinkler through the distribution pattern along a transect. Four cases of operational pressure heads were adopted. Figure 2 shows the operational schematic of the pressure head changes: two cases for constant pressure heads (A and C) and two cases for cyclic pressure head variation (B and D). The values of the operational pressure heads and the operation time for a single cycle were determined such that the volume of water discharged from the sprinkler under constant pressure head operation matches that under cyclic pressure head variation operation. In other words, the water volume is identical when operating in both modes (A and B), and likewise, it is similar

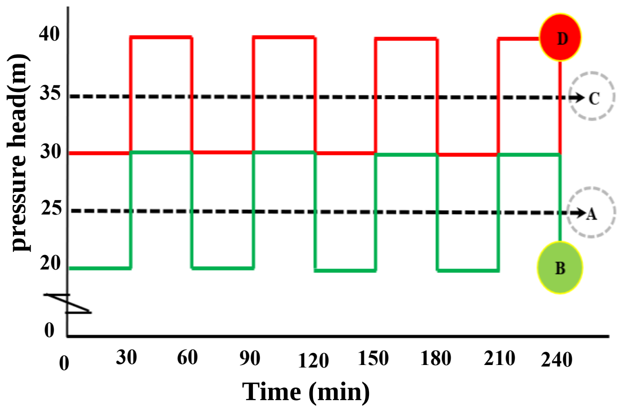


Fig. 2 Operational Diagram for Pressure heads Variations.

when operating in modes (C and D).

Figure 3 illustrates the cylindrical tank and water supply system, where water is supplied from a tank in the laboratory to a pump with an appropriate capacity to provide the required

Fig. 3 Cylindrical Tank and Water Supply System.

pressure head. This is done through a pipe to a cylindrical tank lined internally with a layer of wood shavings. The cylindrical tank is centered with a sprinkler riser on which a rotating sprinkler head is mounted, with an opening in the upper part of the cylindrical tank to discharge spray water. There is a pump at the bottom of the cylindrical tank to return the accumulated water inside it to the main tank, as shown in Figures 4 and 5. Water catch cans were

Fig. 4 The cylindrical tank.

Fig. 5 The iron stand for the sprinkler inside the cylindrical tank.

placed along two rays at two different levels of distances (heights) from the sprinkler nozzle so that the sprinkler riser height on the first ray is 150 cm and the height of the sprinkler riser along the second ray is 10 cm, as shown in Figure 6. The pressure

Fig.6 The cylindrical tank and water collection containers along the wetted radius for two riser heights 10 cm and 150 cm.

head is controlled through three pipes, each containing two valves: a gate valve and a ball valve (Figure 7). The ball valve controls the pressure head and returns excess water to the main tank, and the gate valve is for rapid switching between pressure heads.

Fig. 7 The pressure control valves.

3. RESULTS ANALYSIS

Using the laboratory test data for water distribution of a single sprinkler along the ray, and based on what is shown in Figure 1, the water distribution depths for the first quarter were determined. Due to the absence of wind, there is symmetry in the water distribution, which leads us to obtain the single sprinkler water distribution pattern shown in Figure 8. Appropriate spacing was selected to obtain the field water distribution pattern using Excel software for the triangular and rectangular arrangements of the sprinklers. Figure 9 shows the field water distribution pattern for the 8m × 8m spacing for an Ardent-type sprinkler for the rectangular and triangular arrangements. Christiansen's uniformity coefficient was calculated using the formula shown in Eq. (1).

			0.4	**0.9**	**1.1**	**1.1**	**0.9**	**0.4**			
		0.9	**1.5**	**2.2**	**2.7**	**2.7**	**2.2**	**1.5**	**0.9**		
	0.9	**1.8**	**3**	**3.5**	**3.4**	**3.4**	**3.5**	**3**	**1.8**	**0.9**	
0.4	**1.5**	**3**	**3.4**	**3.4**	**3.5**	**3.5**	**3.4**	**3.4**	**3**	**1.5**	**0.4**
0.9	**2.2**	**3.5**	**3.4**	**3.3**	**3**	**3**	**3.3**	**3.4**	**3.5**	**2.2**	**0.9**
1.1	**2.7**	**3.4**	**3.5**	**3**	**2.7**	**2.7**	**3**	**3.5**	**3.4**	**2.7**	**1.1**
1.1	**2.7**	**3.4**	**3.5**	**3**	**2.7**	**2.7**	**3**	**3.5**	**3.4**	**2.7**	**1.1**
0.9	**2.2**	**3.5**	**3.4**	**3.3**	**3**	**3**	**3.3**	**3.4**	**3.5**	**2.2**	**0.9**
0.4	**1.5**	**3**	**3.4**	**3.4**	**3.5**	**3.5**	**3.4**	**3.4**	**3**	**1.5**	**0.4**
	0.9	**1.8**	**3**	**3.5**	**3.4**	**3.4**	**3.5**	**3**	**1.8**	**0.9**	
		0.9	**1.5**	**2.2**	**2.7**	**2.7**	**2.2**	**1.5**	**0.9**		
			0.4	**0.9**	**1.1**	**1.1**	**0.9**	**0.4**			

Fig. 8 Water Distribution Pattern of a Single Ardent Sprinkler at a Constant Pressure Head of 25m.

$$UC\% = \left(1-\frac{\sum\left|R_i-\bar{R}\right|}{\sum R_i}\right)\times 100\% \quad .... (1)$$

Where UC: Christiansen's uniformity coefficient

$\bar{R}$: Average water depth.

R_i: Water depth reaching the ground in the grid cell**.**

18.36	**17.75**	**17.75**	**18.36**
17.75	**15.93**	**15.93**	**17.75**
17.75	**15.93**	**15.93**	**17.75**
18.36	**17.75**	**17.75**	**18.36**

(a) rectangular arrangement

18.94	**17.09**	**16.59**	**17.16**
17.16	**16.59**	**17.09**	**18.94**
17.16	**16.59**	**17.09**	**18.94**
18.94	**17.09**	**16.59**	**17.16**

(b) triangular arrangement

Fig. 9 Field Water Distribution Pattern of an Ardent Sprinkler Under a Pressure Head of 25 m and a Riser Height of 150 cm for Rectangular and Triangular Arrangements.

4. DISCUSSION

4.1 Water Distribution Pattern of a Single Sprinkler:

Effect of Cyclic Pressure Head Variation on Water Distribution Pattern:

Figures (10-13) show the water distribution patterns for a single sprinkler under constant operating pressure heads of 25 m and 35 m and cyclic pressure head variations of (20-30) m and (30-40) m in both cases of riser height 10 cm and 150 cm and for different sprinkler heads (Ardent, Weather TEC 16-10, Rain Bird 20A, Claber). Generally, there is a match between the water distribution patterns of a single sprinkler in the case of operation under a constant pressure head and its equivalent in operation with a cyclic pressure head variation, and the biggest difference did not lead to a noticeable difference in the water distribution uniformity. This is consistent with the results mentioned in [13]. This may be because the range of the operating pressure head changing is within the limits specified by the sprinkler head manufacturer.

Effect of Sprinkler Riser Height on Water Distribution Pattern:

Figures (14-17) show the water distribution patterns of a single sprinkler for the two cases of riser height 10 cm and 150 cm and under constant operating pressure heads of 25 m and 35 m and for different sprinkler heads (Ardent, Weather TEC 16-10, Rain Bird 20A, Claber). It is evident from these figures that the sprinkler riser height affects the wetting pattern. As the height increases, the spray water distribution pattern shifts away from the sprinkler so that the average depths representing the water distribution pattern near the sprinkler head decrease, meaning that there is an increase in the spray throw, which leads to a larger wetted area covered by the sprinkler.

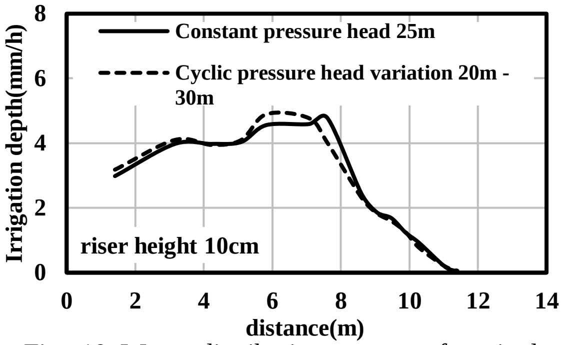
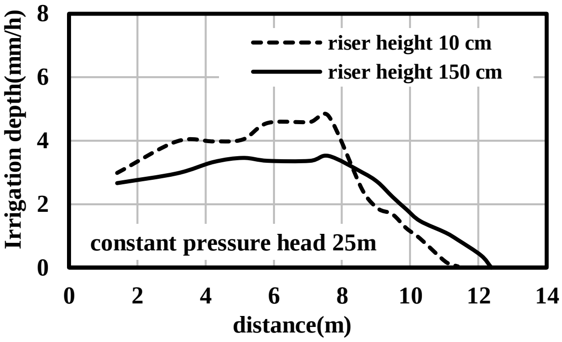


Fig. 10 Water distribution pattern of a single Ardent sprinkler under constant and cyclic varying pressure loads at a riser height of 10 cm.



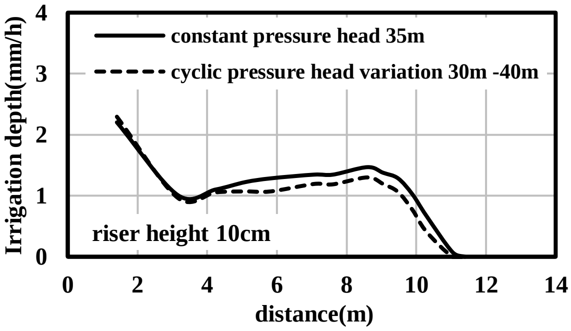


Fig. 11 Water distribution pattern of a single Weather TEC 10-16 sprinkler under constant and cyclic varying pressure loads at a riser height of 10 cm.

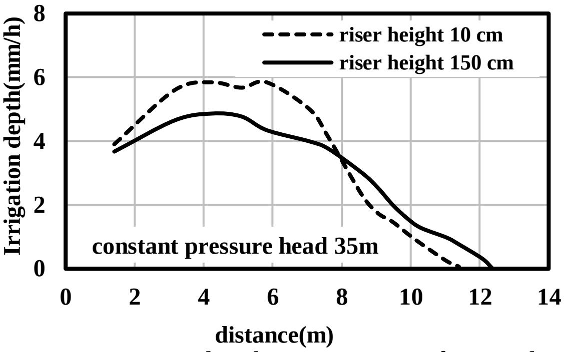


Fig. 14 Water distribution pattern of a single sprinkler (Ardent) at 10 cm and 150 cm of sprinkler riser heights under 25 m and 35 m operating pressure heads.

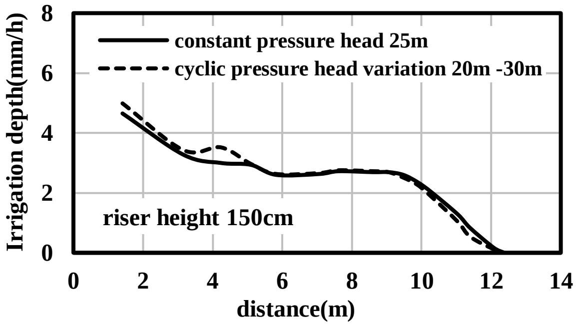
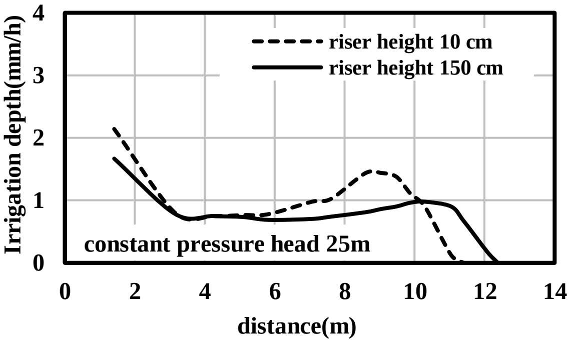


Fig. 12 Water distribution pattern of a single Rain Bird 20A sprinkler under constant and cyclic varying pressure loads at a riser height of 150 cm.



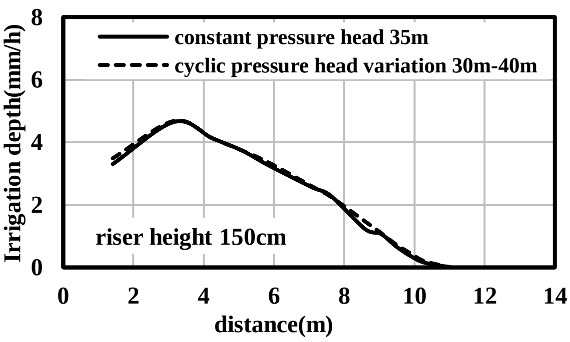


Fig. 13 Water distribution pattern of a single Claber sprinkler under constant and cyclic varying pressure loads at a riser height of 150 cm.

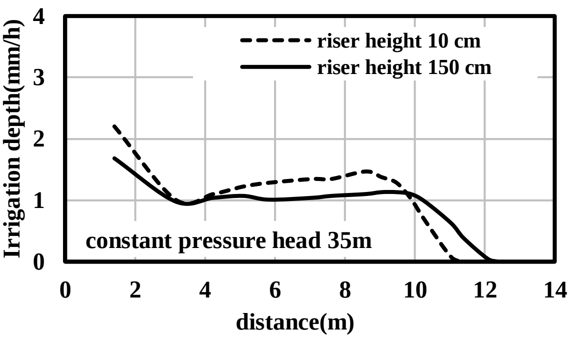


Fig. 15 Water distribution pattern of a single sprinkler (Weather TEC 10-16) at 10 cm and 150 cm of sprinkler riser heights under 25 m and 35 m operating pressure heads.

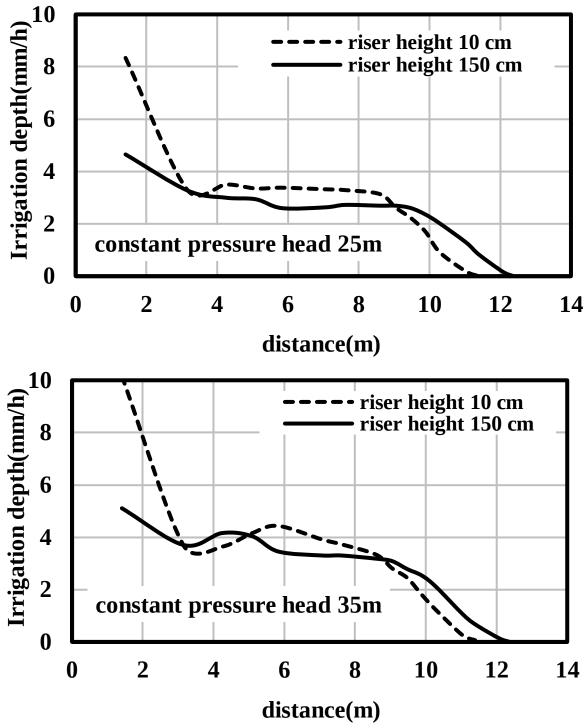


Fig. 16 Water distribution pattern of a single Rain Bird 20A sprinkler at 10 cm and 150 cm of sprinkler riser heights under 25 m and 35 m operating pressure heads.

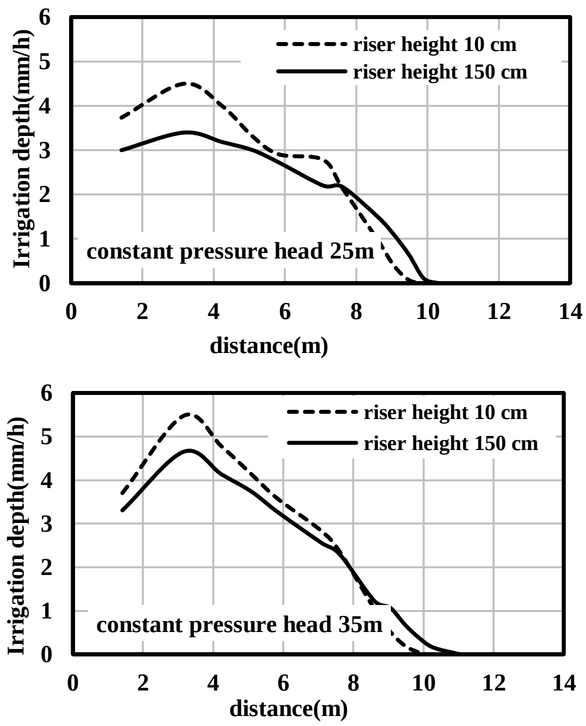


Fig. 17 Water distribution pattern of a single Claber sprinkler at 10 cm and 150 cm of sprinkler riser heights under 25 m and 35 m operating pressure heads.

This is consistent with what was mentioned in [19], [20] as a result of the increased wetted area due to an increase in sprinkler riser higher, the water depth decreases for the same volume of irrigation water

Effect of Pressure Head on Water Distribution Pattern:

Figures (18-21) show the water distribution patterns of a single sprinkler under constant operating pressure heads of 25 m and 35 m and for the two cases of riser height 10 cm and 150 cm and different sprinkler heads (Ardent, Weather TEC 16-10, Rain Bird 20A, Claber). The average irrigation depth increases with increasing pressure head and clearly to a certain distance from the sprinkler location. It is almost constant or decreases slightly compared to what it is at the lower pressure head due to the increase in application rate and for the same covered area and the range of throw was constant with the change in the pressure head for the sprinkler heads under research, where the operating pressure heads are within the range specified by the manufacturer, and this is consistent with what was mentioned by [6], [7].

4.2 Water Distribution Uniformity:

Based on the water distribution patterns of a single sprinkler resulting from laboratory tests under the two constant operating pressure heads and for the two cases of sprinkler riser height and the four sprinkler heads, 288 patterns of field water distribution were determined with appropriate spacing. These patterns included 12 spacing for the rectangular arrangement: (6×6, 6×12, 8×8, 8×12, 8×16, 10×10, 10×16, 10×20, 12×12, 12×16, 14×14, 16×16) and 6 spacing for the triangular arrangement: (8×8, 8×12, 8×16, 12×12, 12×16, 16×16). This spacing is equal to 40% - 60% of the wetted diameter [26]. The Christiansen's uniformity coefficient was calculated from Equation (1) for these patterns. Tables (1-4) show Christiansen’s uniformity coefficient UC for different spacing for the rectangular arrangement of sprinklers and different sprinkler riser heights at two cases of constant operating pressure heads and four sprinkler types. Tables (5-8) also show Christiansen's uniformity coefficient UC for different spacing for the triangular arrangement of sprinklers and different riser heights at two cases of constant operating pressure heads and four sprinkler types.

Effect of Sprinkler Riser Height on Water Distribution Uniformity:

It is clear from Tables (1-8) that there is an increase in the Christiansen's uniformity coefficient due to increasing the sprinkler riser height from 10 cm to 150 cm. This increase varies according to the

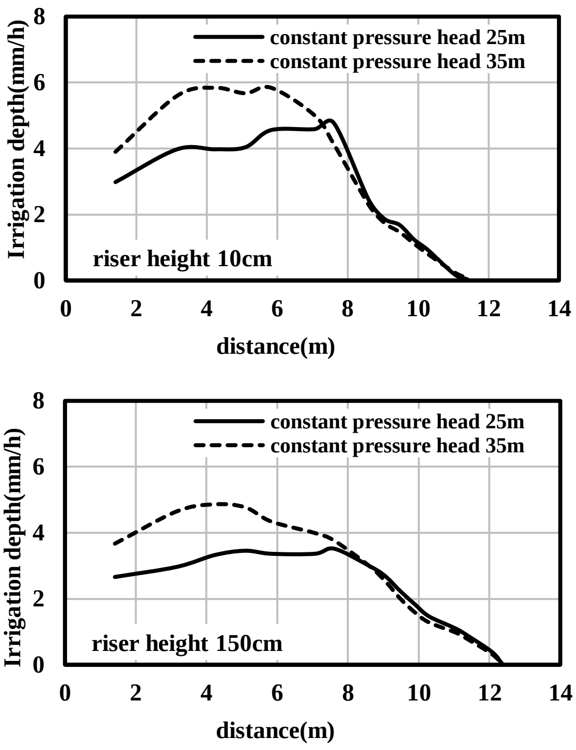


Fig. 18 Water distribution pattern of a single Ardent sprinkler at 10 cm and 150 cm of sprinkler riser heights under 25 m and 35 m operating pressure heads.

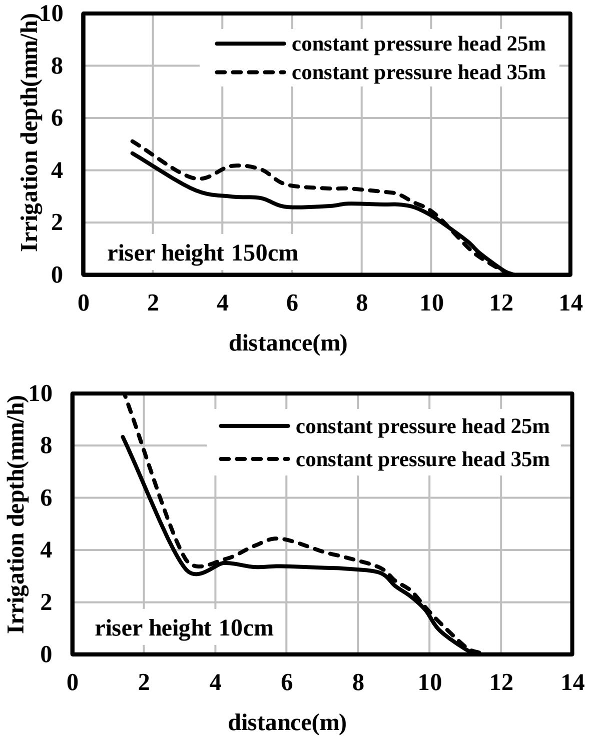


Fig. 20 Water distribution pattern of a single Rain Bird 20A sprinkler at 10 cm and 150 cm of sprinkler riser heights under 25 m and 35 m operating pressure heads.

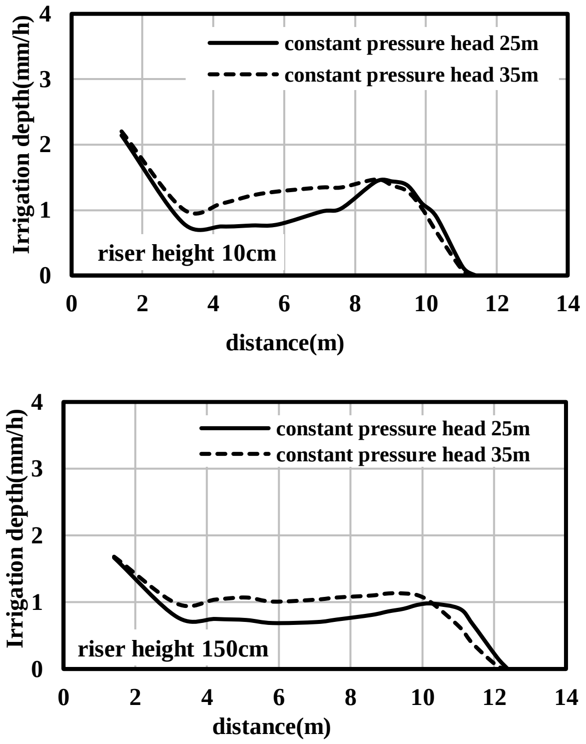


Fig. 19 Water distribution pattern of a single Weather TEC 10-16 sprinkler at 10 cm and 150 cm of sprinkler riser heights under 25 m and 35 m operating pressure heads.

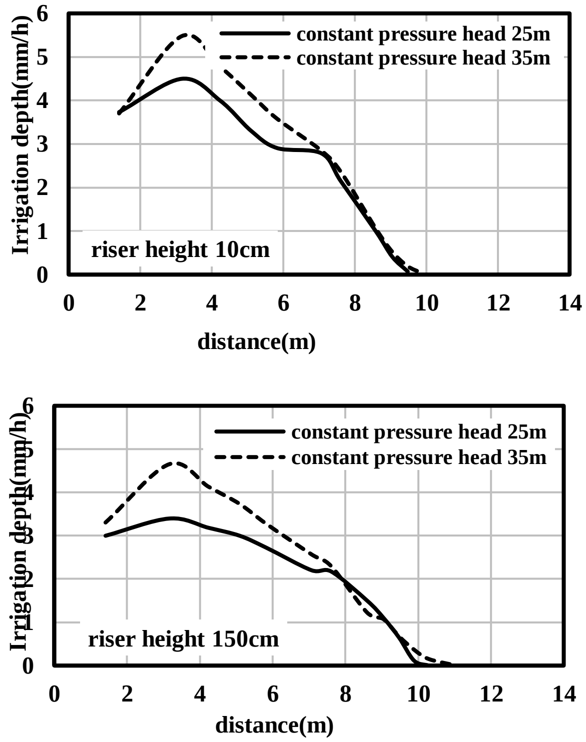


Fig. 21 Water distribution pattern of a single Claber sprinkler at 10 cm and 150 cm of sprinkler riser heights under 25 m and 35 m operating pressure heads.

Table 1: Christensen's uniformity coefficient (UC) for different spacings in the rectangular arrangement of sprinklers and different riser heights under two constant operating pressure heads of the Ardent sprinkler head.

Spacing (S×L) m×m	Pressure Head 25 m		Pressure Head 35 m	
	Riser Height 150cm	Riser Height 10cm	Riser Height 150cm	Riser Height 10cm
6*6	98.4	97.8	98.9	99.3
6*12	86.6	82.1	89.5	87.6
8*8	95.7	98.5	98.3	94.5
8*12	85.6	81.8	89.3	86.8
8*16	92.2	90.5	97.9	87.9
10*10	90.9	78	90.8	82.7
10*16	91.5	82.3	92.7	79.1
10*20	82.3	65.4	73.9	59.8
12*12	81.6	74.4	86.7	79.6
12*16	84.5	76.5	88.3	79.1
14*14	80.2	75	87.6	81.2
16*16	80.6	76	84.9	77.5

Table 2: Christensen's uniformity coefficient (UC) for different spacings in the rectangular arrangement of sprinklers and different riser heights under two operating constant pressure heads of the Rain bird 20A sprinkler head.

Spacing (S×L) m×m	Pressure Head 25 m		Pressure Head 35 m	
	Riser Height 150cm	Riser Height 10cm	Riser Height 150cm	Riser Height 10cm
6*6	97.6	90.2	97.3	90.6
6*12	92.1	90.2	89.2	89.1
8*8	88.1	85.8	90.9	85.9
8*12	90.3	82.7	90.1	82
8*16	85.5	79.4	88.5	80.7
10*10	94.3	80.8	93	82
10*16	85.0	84.4	88.6	83.7
10*20	83.0	66.2	80.1	66.1
12*12	85.0	84.8	83.9	83.6
12*16	89.4	82	89.4	81.4
14*14	88.1	80.4	86.3	79.8
16*16	82.1	71	82.3	72.3

Table 3: Christensen's uniformity coefficient (UC) for different spacings in the rectangular arrangement of sprinklers and different riser heights under two constant operating pressure heads of the Weather TEC 10-16 sprinkler head.

Spacing (S×L) m×m	Pressure Head 25 m		Pressure Head 35 m	
	Riser Height 150cm	Riser Height 10cm	Riser Height 150cm	Riser Height 10cm
6*6	96.4	92.7	97.5	92.8
6*12	94	82.3	89.9	82.2
8*8	88.8	77.1	87.1	86
8*12	88.0	78.7	88.5	81.1
8*16	80.3	66.1	80.8	77.3
10*10	87.1	83.6	93.2	83.5
10*16	73.0	71.2	80.9	82.1
10*20	77.0	75.6	87.2	75.8
12*12	78.1	74.4	80.3	77
12*16	75.4	73.8	85.8	80.3
14*14	78.6	72.3	83.6	74
16*16	77.2	51.6	76.7	64.1

Table 4: Christensen's uniformity coefficient (UC) for different spacings in the rectangular arrangement of sprinklers and different riser heights under two operating constant pressure heads of the Claber sprinkler head.

Spacing (S×L) m×m	Pressure Head 25 m		Pressure Head 35 m	
	Riser Height 150cm	Riser Height 10cm	Riser Height 150cm	Riser Height 10cm
6*6	99.1	96.3	96.7	96.4
6*12	92.9	95.5	94.1	94.7
8*8	96.3	93.7	94.1	90.5
8*12	90.8	92.3	93.5	91.4
8*16	81.8	72.7	77.8	72
10*10	84.9	85.9	88.8	86.4
10*16	79.9	69.3	75	67.3
10*20	*	*	53.3	*
12*12	89.6	89.2	90.4	86.8
12*16	77.9	73	74.4	69.6
14*14	84.5	*	82.3	77
16*16	75.3	*	71.8	63.9

interaction of the spacing, the arrangement of the sprinklers, the type of sprinkler heads, and the operating pressure head. Table (9) shows the average percentage increase in Christiansen's uniformity coefficient UC due to increasing the sprinkler riser height for the sprinkler heads under research for the rectangular and triangular arrangements of sprinklers at different pressure heads. This increase in water distribution uniformity results from increasing the wetted area covered by the single sprinkler by increasing the sprinkler riser height, which is consistent with what was mentioned in [1], [14], [15]. It is clear from the table that the values of the average percentage from 3.9% to 11.5% for the rectangular arrangement of sprinklers and from 4.7 to 21.7 for the triangular arrangement of sprinklers. According to the average percentage increase for all sprinkler heads in the Christiansen's uniformity increase vary between the type of sprinkler heads,

Table 5: Christensen's uniformity coefficient (UC) for different spacings in the triangular arrangement of sprinklers and different riser heights under two constant operating pressure heads of the Ardent sprinkler head.

Spacing (S×L) m×m	Pressure Head 25 m		Pressure Head 35 m	
	Riser Height 150cm	Riser Height 10cm	Riser Height 150cm	Riser Height 10cm
8*8	95.7	90.5	99.6	95.1
8*12	85.2	79.8	89.3	87.8
8*16	91.8	92	97.7	87.4
12*12	81.6	70.8	83.8	76.9
12*16	82.1	77.5	85.6	78.5
16*16	79.1	83.3	91.7	83.4

Table 6: Christensen's uniformity coefficient (UC) for different spacings in the triangular arrangement of sprinklers and different riser heights under two constant operating pressure heads of the Rain bird 20A head.

Spacing (S×L) m×m	Pressure Head 25 m		Pressure Head 35 m	
	Riser Height 150cm	Riser Height 10cm	Riser Height 150cm	Riser Height 10cm
8*8	90.3	80.2	91.4	80.7
8*12	88.4	81.7	87.6	81.9
8*16	86.3	80.9	89.1	82.7
12*12	90.6	83	86.2	82.4
12*16	86.9	77.3	86.3	77.7
16*16	76.7	76.2	80.4	77.7

coefficient as a result of increasing the sprinkler riser height, the increase in the triangular arrangement is better than that in the rectangular arrangement, as well as at the operating pressure head of 25 m is better than what it is at the operating pressure head of 35 m. The overall average increase in the Christiansen's uniformity coefficient is 8.65% under all influencing factors.

Effect of Pressure Head on Water Distribution Uniformity:

In general, it is also clear from Tables (1-8) that there is a slight increase in the Christiansen's uniformity coefficient due to increasing the operating pressure head from 25 m to 35 m. This increase varies according to the interaction of the spacing, the arrangement of the sprinklers, the type of arrangement of the sprinklers, the type of sprinkler heads, and the sprinkler riser height. Table (10) shows the average percentage increase in Christiansen's uniformity coefficient UC due to increasing the operating pressure head for the sprinkler heads under research for the rectangular and triangular arrangements of sprinklers at

Table 7: Christensen's uniformity coefficient (UC) for different spacings in the triangular arrangement of sprinklers and different riser heights under two constant operating pressure heads of the Weather TEC 10-16 head.

Spacing (S×L) m×m	Pressure Head 25 m		Pressure Head 35 m	
	Riser Height 150cm	Riser Height 10cm	Riser Height 150cm	Riser Height 10cm
8*8	88.9	73.2	89.1	80.4
8*12	93	71.2	86.2	77.5
8*16	80.7	67.2	82.3	77.3
12*12	89.3	77.8	88.1	75.7
12*16	74.6	71.6	82.2	77.6
16*16	69.5	49.6	70.3	65.8

Table 8: Christensen's uniformity coefficient (UC) for different spacings in the triangular arrangement of sprinklers and different riser heights under two constant operating pressure heads of the Claber head.

Spacing (S×L) m×m	Pressure Head 25 m		Pressure Head 35 m	
	Riser Height 150cm	Riser Height 10cm	Riser Height 150cm	Riser Height 10cm
8*8	96.3	94.5	95.4	91.3
8*12	93.2	93.8	94.6	92.4
8*16	81.8	72.7	77.8	72
12*12	84.1	85.3	87.3	86.8
12*16	77.9	73	74.4	69.6
16*16	79.5	67.8	74	64.5

different riser heights. It is clear from the table that the values of the average percentage increase vary between the type of sprinkler heads, as it is negative for the Claber type sprinkler, resulting in a decrease in the Christiansen's uniformity coefficient in both the rectangular and triangular arrangements of sprinklers and at different sprinkler riser heights, while the increase is positive in the rest of the sprinklers and reaches 7.15% for the rectangular arrangement of sprinklers and 12% for the triangular arrangement of sprinklers. According to the average percentage increase for all sprinkler heads in the Christiansen's uniformity coefficient as a result of increasing the operating pressure head, the increase in the triangular arrangement is better than that in the rectangular arrangement, as well as at the riser height of 10 cm is better than what it is at the riser height of 150 cm. The overall average increase in the Christiansen's uniformity coefficient is 1.98% under all influencing factors.

Effect of Sprinkler Arrangement on Water Distribution Uniformity:

Table 9: Percentage increase in the Christiansen's uniformity coefficient (UC) resulting from increasing the sprinkler riser height for the sprinklers under study in rectangular and triangular arrangements at different pressure heads.

Sprinkler type and sprinkler arrangement		Percentage increase in the Christiansen's uniformity coefficient due to an increase in sprinkler riser height at a pressure head of 25 m	Percentage increase in the Christiansen's uniformity coefficient due to an increase in sprinkler riser height at a pressure head of 35 m
rectangular arrangement of sprinklers	Ardent	8.04	9.05
	Rain bird 20A	9.36	8.79
	Weather TEC	11.5	8.19
	Claber	3.9	5.32
	Average	8.2	7.84
Triangular arrangement of sprinklers	Ardent	4.74	7.7
	Rain bird 20A	8.67	7.85
	Weather TEC	21.7	9.61
	Claber	6.06	12.78
	Average	10.29	9.49
Overall average		8.9	8.39

From the comparison between the values of the Christiansen's uniformity coefficient in Tables (1-8) and for the identical spacing for the rectangular and triangular arrangements of sprinklers, Table (11) shows the percentage of the better arrangement in the Christiansen's uniformity coefficient values for the four sprinklers. As an average for all sprinklers, about 70% of the values of the Christiansen's uniformity coefficient in the rectangular arrangement are greater than or equal to the values of the Christiansen's uniformity coefficient in the triangular arrangement, and this is consistent with previous studies in [13], [23], [24] and differs from [25] when the water distribution pattern around the sprinkler is symmetrical.

4.3 spray losses (evaporation):

Spray losses during the laboratory tests of the water distribution pattern of a single sprinkler are limited to evaporation only, as there are no wind currents carrying water droplets outside the test area. Table (12) presents the percentage of spray losses calculated using Eq. (2) [26] for

Table 10: Percentage increase in the Christiansen's uniformity coefficient (UC) resulting from increasing the Constant operating pressure head for the sprinklers under study in rectangular and triangular arrangements at different sprinkler riser heights.

Sprinkler type and sprinkler arrangement		Percentage increase in the Christiansen's uniformity coefficient due to an increase in pressure head at a sprinkler riser height of 10 cm	Percentage increase in the Christiansen's uniformity coefficient due to an increase in pressure head at a sprinkler riser height of 150 cm
rectangular arrangement of sprinklers	Ardent	1.8	2.78
	Rain bird 20A	0.48	0.07
	Weather TEC	7.15	4.33
	Claber	-1.8	-1.6
	Average	1.91	1.4
Triangular arrangement of sprinklers	Ardent	3.36	6.37
	Rain bird 20A	1.4	0.7
	Weather TEC	12	0.98
	Claber	-2.2	-1.9
	Average	3.64	1.54
Overall average		2.49	1.47

sprinkler riser heights of 10 cm and 150 cm, at operating pressures of 25 m and 35 m, and for the sprinkler head types under study.

$$ssl\% = \frac{V_{discharged} - V_{collected}}{V_{discharged}} \times 100 \ldots\ldots (2)[26]$$

Where ssl: sprinkler spray losses

$V_{discharged}$: Volume of water discharged from sprinkler

$V_{collected}$: Volume of water collected in catch cans

It is evident from the table that the evaporation rate is 5.625% at a sprinkler riser height of 10 cm and 8.50% at 150 cm, which represents an increase of 51.1% resulting from the increased riser height. This occurs because the water droplets travel a longer distance before reaching the soil surface which is consistent with [22].

It also found that the average evaporation rate is 6.55% at a pressure head of 25 m and 7.57% at a pressure head of 35 m, representing an

Table 11: Comparison of Christiansen's uniformity coefficient values for four sprinkler heads in rectangular and triangular arrangements.

Sprinkler Type	Percentage of cases where the Christiansen's uniformity coefficient for the rectangular arrangement is greater than or equal to that for the triangular arrangement(%)	Percentage of cases where the Christiansen's uniformity coefficient for the triangular arrangement is greater than or equal to that for the rectangular arrangement(%)
Ardent	70.8	66.7
Rain Bird 20A	70.8	50
Weather tec 10-16	66.7	50
claber	69.6	87
average	69.5	63.4

increase of 15.6% due to increasing the pressure head. This is consistent with [20] because the size of the water droplets becomes smaller with increasing pressure head and thus increases the surface area of the water, and this aligns with what stated by [20].

5. CONCLUSIONS:

This study comprehensively evaluated the performance of 4 sprinklers under various operational parameters. The findings provide critical insights into optimizing water distribution uniformity and managing water losses.

The water distribution patterns of a single sprinkler operating under a constant pressure head were found to be highly comparable to those of its equivalent operating with a cyclic pressure head variation, and the highest difference observed was minor and did not lead to a noticeable difference in Christiansen's uniformity coefficient (UC). This suggests that minor cyclical pressure head fluctuations, which are common in many field systems, may not significantly impair irrigation performance, offering some operational flexibility.

The physical geometry of the spray was significantly influenced by the operational setup. By increasing the sprinkler riser height, the shape of the spray water distribution pattern was characterized by a lower average depth and an increased wetting radius. Conversely, as the pressure head was increased, the shape of the spray water distribution pattern resulted in greater depths near the sprinkler location, followed by a region

Table 12: Percentage of spray losses (evaporation) during the water distribution pattern test for sprinkler riser height at 10 cm and 150 cm for 25 m and 35 m operating pressure heads to the sprinkler types under investigation.

Sprinkler Type	Pressure Head 25m		Pressure Head 35m	
	Riser Height 10cm	Riser Height 150cm	Riser Height 10cm	Riser Height 150cm
Weather TEC 10-16	6.09	9.55	6.56	10.18
Rain Bird 20A	7.39	8.83	7.92	9.77
Ardent	3.19	4.86	4.71	6.18
Claber	3.32	9.2	5.81	9.41
Average	5	8.11	6.25	8.89

where the depth was almost constant or decreased slightly at further distances.

In terms of irrigation efficiency, there is an increase in the Christiansen's uniformity coefficient due to the increase in the sprinkler riser height. The increase in the triangular arrangement is better than that in the rectangular arrangement. Besides, the increase was more significant at the lower operating pressure head than at the higher operating pressure head, and the overall average increase in the Christiansen's uniformity coefficient is 8.65% under all influencing factors, highlighting riser height as a primary tool for enhancing uniformity, especially in low-pressure systems.

There is a slight increase in the Christiansen's uniformity coefficient as a result of increasing the operating pressure head, and the increase in the triangular arrangement is better than in the rectangular arrangement, and the effect was more pronounced at the lower sprinkler riser height which is better than what it is at the higher sprinkler riser height. The overall average increase in the Christiansen's uniformity coefficient is 1.98% under all influencing factors. This indicates that while increasing pressure head is beneficial, it yields diminishing advantages for uniformity, particularly for systems already using high risers.

Interestingly, under conditions that produce a symmetrical water distribution pattern around the sprinkler, 70% of Christiansen's uniformity coefficient values for the rectangular arrangement were greater than or equal to those in the triangular arrangement, this finding suggests that the theoretical superiority of the triangular arrangement may be conditional and arrangement choice should consider prevailing environmental conditions.

While these operational adjustments improved uniformity, they were accompanied by the significant negative consequence of increased water losses, the spray losses increased by a substantial 52.1% due to increasing the sprinkler riser height and 15.6% due to increasing the pressure head. This underscores the central challenge in sprinkler system design: balancing the goal of high uniformity with the imperative of water conservation by minimizing spray and evaporation losses.

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تأثير ارتفاع قصبة المرشة وتغير شحنة الضغط الدوري على نمط توزيع الماء لأنظمة الري بالرش الشبكية

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الملخص

يُمثل الضغط التشغيلي أحد العوامل الحاسمة في تفتيت بثق الماء وتشتيته إلى قطرات، كما تُسهم قصبة المرش في تهدئة جريان الماء واستقراره. يهدف هذا البحث إلى دراسة تأثير كل من ارتفاع قصبة المرشة وتغيّر شحنة الضغط الدوري على نمط توزيع الماء لمرشة مفردة، فضلًا عن تحليل تداخل هذه العوامل مع الفواصل بين المرشات وللترتيبين الرباعي والثلاثي للمرشات. أظهرت النتائج تشابهًا كبيرًا في أنماط توزيع الماء بين التشغيل تحت شحنة ضغط ثابت والتشغيل تحت شحنة ضغط متغير دوريًا، دون أن تُحدث الفروقات المسجلة تغييرًا يُذكر في معامل تناسق كريستنسن (UC). وقد أدت زيادة ارتفاع قصبة المرشة إلى توزيع الماء بأعماق أقل مع زيادة في نصف القطر المبتل، ولوحظت أكبر زيادة في معامل تناسق كريستنسن (UC) في الترتيب الثلاثي عند أدنى ضغط تشغيلي، حيث بلغ متوسطها 8.65%. وعلى صعيد آخر، نتج عن زيادة شحنة الضغط أعماق توزيع أكبر بالقرب من موقع المرشة، مع ميل النمط للاستقرار بعد ذلك. بلغت الزيادة الإجمالية في معامل تناسق كريستنسن (UC) لكافة المتغيرات المدروسة 1.98%، كما تبين أن 70% من قيمه في الترتيب الرباعي كانت أعلى من نظيراتها في الترتيب الثلاثي أو مساوية لها.

الكلمات الداله :

قصبة المرشة، شحنة الضغط التشغيلية، تناسق الارواء، أنظمة الرش الشبكية، الترتيب الرباعي والثلاثي.