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The Effect of Sprinkler head Rotation Speed and Cyclically Pressure Head Variation on The Uniformity of Water Distribution for Stationary Sprinkler Irrigation Systems

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ABSTRACT:

The research includes studying the effect of sprinkler rotation speed and cyclic pressure head variation on the pattern and degree of uniformity of water distribution and its interaction with the spacings between the sprinklers and their rectangular and triangular arrangement of four heads of different sprinklers. The research included conducting laboratory experiments to find the pattern of water distribution for a single sprinkler along a ray representing the radius of the wetting circle that its center is the sprinkler for two constant and variable pressure heads, three rotation rates (fast, moderate and slow) of the sprinkler head. Then, the pattern of field distribution of sprinkling water was determined, and the degree of uniformity of water distribution interm of uniformity coefficient and distribution uniformity coefficient were calculated. The results showed that there is no effect on the water distribution pattern when operating with a constant pressure head or operating with cyclically variation pressure head at each of the sprinkler rotation speed levels for all sprinkler heads under study. It was noted that the average depth of the water distribution pattern increased, and the wetted area decreased at the fast rotation rate of the sprinkler and vice versa. The study provided empirical equations for estimating uniformity coefficient and distribution uniformity coefficient at different speeds of sprinkler rotation.

Key words:
Grid sprinkler system, uniformity coefficient, sprinkler head rotation, pressure head variation, sprinkler arrangement.

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1. INTRODUCTION

Any improvement in the efficiency of water use contributes to solving the problem of water scarcity, and since the uniformity of water has a great impact on productivity and irrigation efficiency, any increase in the uniformity of water will lead to increased productivity and water savings. Therefore, it has become necessary to study any factor that affects the uniformity of water distribution. Therefore, improving the uniformity of water distribution represents a basic goal for irrigation systems [1]. The most important factors affecting the uniformity of water distribution for stationary sprinkler systems include sprinkler head factors, which are the angle of the sprinkler, the speed of the sprinkler rotation, the pressure head rate at the sprinkler, and the number and types of sprinklers, then distribution system factors, which are the intervals between sprinklers, the height of the sprinkler riser pipe, and the variation of the pressure head during operation, in addition to climatic factors, which are the speed and direction of the wind, and finally administrative factors, which are the operating time of the sprinkler system and the angle of the sprinkler riser pipe inclination [2]. The previous researches and studies did not address the effect of cyclically variation pressure and the speed of the sprinkler rotation on the uniformity of water distribution and its interference with other factors, which may be negative or positive. Therefore, this research aims to know the effect of cyclically variation pressure and the speed of the sprinkler rotation on the uniformity of water distribution and its interference with the intervals between the sprinklers and the rectangular and triangular arrangement of the sprinklers and different sprinkler heads. The research consists of an introduction, a review of the literatures related to the study problem, and laboratory tests. Then the results are analyzed and discussed, as well as concluding the research with conclusions.

2. PREVIOUS STUDIES

In general, there are many studies and researches that have addressed the factors affecting the uniformity of water distribution and have shown the following: There is an increase in the uniformity coefficient as a result of the increase in both the height of the sprinkler riser pipe or the pressure head, and the effect of the pressure head on the uniformity coefficient is greater than the effect of the height of the sprinkler riser pipe [3]. The triangular arrangement of sprinklers does not improve the uniformity of water distribution compared to the rectangular arrangement [4]. Wind speed influences the location of the sprinkler lateral relative to the prevailing wind direction to obtain the best uniformity in water distribution. Also, the uniformity of the overall sprinkler water distribution improves when the wind speed and direction change for successive irrigations [5]. A study [6] was conducted on the irregularity of sprinkler head rotation and water distribution, as most sprinklers are commercial and asymmetrical, which causes irregular rotation and negatively affects the water distribution pattern and irrigation uniformity. Five types of sprinkler heads with different nozzle diameters and under two operating pressure heads were studied. The results showed that the maximum value of the relative deviation of sprinkler rotation It is around 20% for most sprinklers with impact arms, as the maximum standard recommended MRD value should not exceed 12%, and the maximum relative deviation of the sprinkler rotation MRD value increases with increasing the angle of inclination of the sprinkler riser pipe from the vertical. The change in irrigation uniformity in the case of using two types of sprinkler heads for the network varies between increasing and decreasing from what it is when using one type, depending on the interferences in the sprinkler heads arrangement and the sprinkler water distribution patterns in addition to the sprinkler head spacings [7]. In general, the uniformity coefficient decreases in the case of low pressure and greater distance between the sprinklers [8]. The uniformity of soil moisture content is about 20% higher than the uniformity of sprinkler irrigation water distribution on the soil surface [9]. The researchers in [10] conducted a study to determine the performance of sprinkler irrigation systems under different pressures and under conditions of variable wind speed. The water distribution patterns for different sprinkler heads were determined at different pressures, i.e. at the minimum, average and maximum pressure, and under conditions of variable wind speed. The value of the uniformity coefficient and the uniformity of water distribution for each sprinkler head were determined. They concluded from the study the variation in the values of the uniformity coefficient and the uniformity of water distribution. In a study [11] to evaluate the uniformity coefficient of sprinklers for irrigation systems under different field conditions, the different proposed uniformity coefficients were evaluated and the effect of the field conditions obtained for those coefficients was verified. Sprinkler uniformity tests were conducted using a rain gauge to measure the uniformity coefficients for ten fields irrigated by sprinkler irrigation systems. The results showed that all selected fields differed in the prevailing conditions such as wind speed, sprinkler nozzle diameter and sprinkler head type, sprinkler riser height, operating pressure, and sprinkler spacings. By calculating the uniformity coefficient, the results indicated that the field effect should be considered in the statistical model. The study confirmed conclusively that the application of different uniformity coefficients depends on the field conditions and that any specific uniformity coefficient is suitable for specific field conditions. Spray uniformity tests were conducted using a rain gauge to measure the uniformity coefficients for ten fields irrigated by sprinkler irrigation systems. The results showed that all selected fields differed in the prevailing conditions such as wind speed, sprinkler diameter and type, sprinkler shaft height, operating pressure, and sprinkler intervals. By calculating the uniformity coefficient, the results indicated that the field effect should be considered in the statistical model. The study confirmed conclusively that the application of different uniformity coefficients depends on the field conditions and that any specific uniformity coefficient is suitable for specific field conditions. The square arrangement outperforms the rectangular arrangement in all evaluation criteria when the pressure head is constant [12]. The value of the uniformity coefficient increases with the increase in pressure head for all types of sprinklers [13]. There is a difference in the rotational uniformity of some sprinklers and a difference between them in the spray rate because of this [14]. There is an increase in the spray range on the surface of the ground sloping downwards and a decrease on the surface of the ground sloping upwards [15]. In a study conducted by researchers in [16] to evaluate the hydraulic performance characteristics of a newly designed dynamic sprinkler at different nozzle diameters and pressures, MATLAB R2014a was used to calculate the uniformity coefficient. The results showed that all nozzle diameters produced parabolic profiles, while the 5.5 mm diameter was flat at a low pressure of 150 kPa. This means that the 5.5 mm diameter can improve the irregular distribution of water and provide water for fields irrigated by sprinkler. The study also showed that the highest value of the uniformity coefficient was 86% at a pressure of 150 kPa and a 5.5 mm diameter. The results also showed that using a 5.5 mm diameter would be optimal because the water droplet size is smaller and thus spray losses will be reduced. In a study conducted by the researchers in [17] to evaluate the performance of the sprinkler irrigation system under field conditions and measure the uniformity of water distribution for a single sprinkler and four overlapping sprinklers from the water collected in the catch cans installing in the square grids centers (3m x 3m) under two operating pressures of 250 kPa and 300 kPa, the average irrigation uniformity coefficient under field conditions for the spacing (18m x 18m) at a pressure of 300 kPa was equal to 63% and at a pressure of 250 kPa it was equal to 53%, i.e. less than the recommended value of 75%. Also, the Christensen uniformity coefficient of spray water distribution at pulse pressure is about 10% higher than at constant pressure [18]. The researchers in [19] showed that the uniformity coefficient increases with the increase in pressure head and that the amount of increase varies according to the type of sprinkler head used and the spacings between the sprinklers and that the uniformity coefficient of the whole system is almost identical to the uniformity coefficient at the operating pressure head rate for all spacings between the sprinklers. The researchers in [20] concluded that the highest values of the uniformity coefficient and the distribution uniformity coefficient are 84% and 78% under a pressure head of 200 kPa and a height of 1 m in the morning and concluded higher uniformity values at low wind speed, high relative humidity and low temperature. Increasing the angle of the sprinkler nozzle leads to an increase in the water distribution uniformity coefficient, and 70% of the uniformity coefficients for the rectangular arrangement are greater than or equal to the value of the triangular arrangement, and there are slight differences between the two-water distribution patterns in the case of constant pressure and cyclically variation pressure operation [21]. In a study to find out the best conditions for operating the sprinkler, the researcher in [22] conducted a study with different operating pressures and different heights to find the shape of the water distribution pattern when operating it under conditions of no wind and how to simulate it to determine the best height for the sprinkler riser pipe. A simulation was made of the uniformity of water distribution by collecting water in water collection cans. The study concluded that the best pressure for operating the sprinkler is 250 kilopascals and the height of the sprinkler riser is 1.5 meters. Researchers in [23] showed that the relationship between the spray angle and its maximum height at different pressure heads is equivalent to the second-order parabolic equation. Empirical relationships were developed to estimate the uniformity coefficient for single and double alternate setting of sprinkler laterals as well as the distribution coefficient for single and double alternate setting of sprinkler laterals [24]. The uniformity coefficient decreases with the increase in the slope of the ground surface, and the shape of the sprinkler water distribution pattern does not change with the change in the slope of the

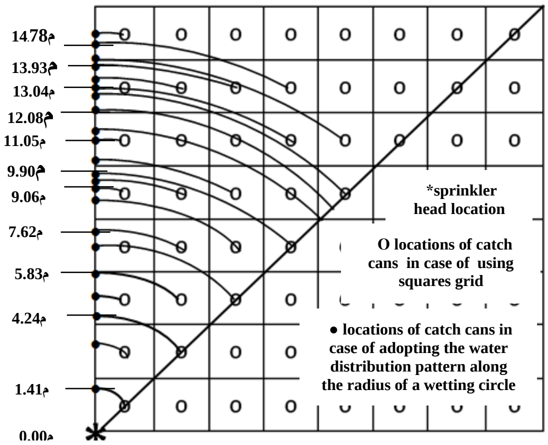

Figure (1): Water distribution pattern of a single sprinkler resulting along the radius of a wetting circle centered by the sprinkler head.

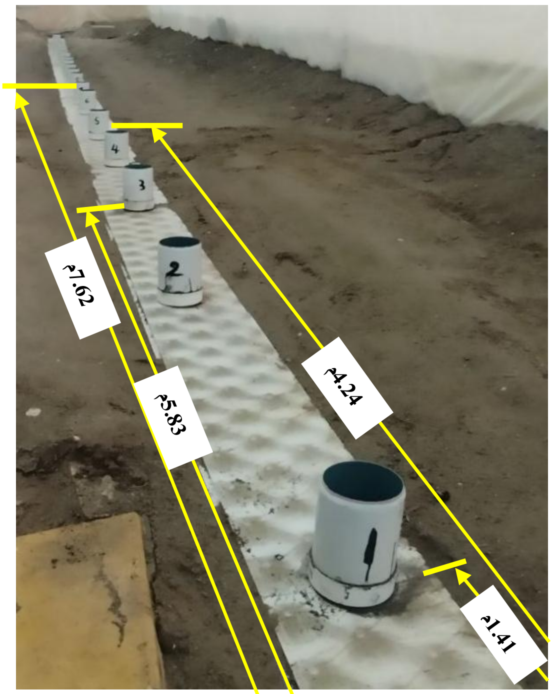

Figure (2): Realistic image of water catch cans.

ground, but the average depth of the water decreases, and the spray range increases the more the ground level decreases away from the sprinkler, and vice versa [25]. When there is no wind and the water distribution pattern around the sprinkler is symmetrical, the diameter of the water collection cans has no effect on the water distribution pattern, and both the uniformity coefficient and the distribution coefficient increase with the increase in the spacing between the water collection cans [26,27]. When the operating pressure head at the spray nozzle increases, the spray discharge and the wetting radius increase [28].

3. LABORATORY TESTS:

In order to study the effect of the sprinkler rotation speed and the cyclically variation pressure head on the uniformity of water distribution for stationary sprinkler systems, it is required to obtain data for the water distribution pattern for a single sprinkler and for several different sprinkler heads at different sprinkler rotation speeds and in two cases of pressure head, the first at the pressure head rate constant during the test and the second cyclically variation between a large pressure head and a small pressure head so that the volume of water coming out of the sprinkler is identical in both cases. This was done by adopting the water distribution pattern along the radius of a wetting circle centered by the sprinkler head. Figure (1) shows the water catch cans that were placed along the radius at distances that match the tests that are carried out by squares grid with locating the water catch cans in their center with spacings of 2 m x 2 m. Figure (2) shows a realistic image of the water catch cans inside the laboratory. Four sprinklers and a water tank were used.

A main pump, then a pipe system for supplying water, ending in a cylindrical tank lined with sawdust, closed with a rectangular opening for the spray water to exit, in which a riser pipe and sprinkler head are fixed. The pressure head is controlled by ball valve and a gate valve through three short pipes leading to the water return pipe to the supply tank as shown in Figure (3), Figure (4) and Figure (5) for ease and speed of switching between high- and low-pressure heads in addition to the fixed pressure head. The constant pressure head is 27.5 m and the test time is 240 minutes, but when operating with a cyclically variation pressure head, the pressure head is changed according to the heads and the time adopted within the cycle until the end of the total test time, as the pressure head is changed from 20 m to 35 m and for each head, the operation was for a time of 30 minutes. Six tests were conducted for each type of sprinklers used at a moderate rotation rate, a fast rotation rate and a slow rotation rate in two cases by adopting a

Figure (3): Supply pipe, pressure control, water return pipe, and excess water return pipe.

Figure (4): Valve control box for pressure head change.

Figure (5): Water supply tank and main pump.

Figure (6): Accelerating the rotation of the sprinkler by tightening the spring.

Figure (7): Slowing down the rotation of the sprinkler by adding weight to the impact arm.

constant pressure head and a variable pressure head, i.e. the result of the tests is 24 patterns of a single sprinkler water distribution. The two sprinklers, Weather tec 10-16 and Rain bird 20A, were their rotation accelerated using a piece of plastic, and the sprinklers, type SER and Atak by means of a spring connected to the sprinkler as shown in Figure (6). All types of sprinklers were their rotation slowed down by using a weight weighing 200 gm by connecting it to the sprinkler's impact arm as shown in Figure (7). The tests included 24 tests, six tests for each sprinkler, three in the case of a constant pressure head and three in the case of a variable pressure head, at a fast, moderate and slow sprinkler head rotation rate.

				0.3	1.9	1.9	0.3				
		0.3	7.4	10.5	10.6	10.6	10.5	7.4	0.3		
	0.3	9.8	10.9	9.7	9.4	9.4	9.7	10.9	9.8	0.3	
	7.4	10.9	9.4	9.0	8.0	8.0	9.0	9.4	10.9	7.44	
0.3	10.5	9.7	9.0	6.7	6.8	6.8	6.7	9.0	9.7	10.5	0.3
1.9	10.6	9.4	8.0	6.8	11.1	11.1	6.8	8.0	9.4	10.6	1.9
1.9	10.6	9.4	8.04	6.8	11.1	11.1	6.8	8.0	9.4	10.6	1.9
0.3	10.5	9.7	9.0	6.7	6.8	6.8	6.7	9.0	9.7	10.5	0.3
	7.4	10.9	9.4	9.0	8.0	8.0	9.0	9.4	10.9	7.4	
	0.3	9.8	10.9	9.7	9.4	9.4	9.7	10.9	9.8	0.3	
		0.3	7.4	10.5	10.6	10.6	10.5	7.4	0.3		
				0.3	1.9	1.9	0.3				

Figure (8): Water distribution pattern of a single Weather tec 10-16 sprinkler in mm at a moderate rotation rate and constant pressure head.

4. ANALYSIS OF RESULTS:

The data resulting from the laboratory tests represent the water distribution patterns of the sprinklers along a radius representing the radius of the wetting circle centered by the sprinkler head, and each pattern is equivalent to a quarter of the wetting area covered by the single sprinkler, as shown in Figure (1). The data included water distribution patterns for single sprinklers and for different rates of sprinkler rotation speed, fast, moderate, and slow, for the cases of constant and cyclically variable operating pressure head, for four different types of sprinkler heads. Appropriate spacings were chosen between the sprinklers, which represent approximately 50-60% of the diameter of the wetting circle covered by the single sprinkler according to [28]. By adopting 12 single sprinkler water distribution patterns at a constant operating pressure head, 14 spacings for the rectangular sprinklers arrangement, and 12 spacings for triangular sprinklers arrangement, 312 patterns for the field distribution of sprinkler water were found with the help of the Excel program, which represents the distribution pattern between four adjacent sprinkler heads in the case of operating the entire sprinkler system. Then, the degree of uniformity of the sprinkler water distribution for the field distribution patterns was found using the Christensen uniformity coefficient (UC) Distribution uniformity coefficient (DU) It is calculated as shown in Figures (8 and 9). The uniformity coefficient UC and the distribution uniformity DU were calculated using the following expressions:

62.0	**55.4**	**55.4**	**62.0**
55.4	**34.9**	**34.9**	**55.4**
55.4	**34.9**	**34.9**	**55.4**
62.0	**55.4**	**55.4**	**62.0**

$\bar{R}$= 51.9, $\sum R_i$= 831.3

$\sum |R_i - \bar{R}|$ = 136.32,

UC=83.6, DU= 67.2

Moderate rotation rate and constant pressure head for quaternary arrangement

69.9	**45.9**	**44.4**	**47.5**
47.5	**44.4**	**45.9**	**69.9**
47.5	**44.4**	**45.9**	**69.9**
69.9	**45.9**	**44.4**	**47.5**

$\bar{R}$= 51.9, $\sum R_i$= 831.3

$\sum |R_i - \bar{R}|$ =144 ,

UC= 82.7, DU= 85.5

Moderate rotation rate and constant pressure head for the triangular arrangement

Figure (9): Field water distribution pattern in millimeters for Weather tec 10-16 sprinkler heads at moderate rotation rate and constant sprinkler pressure head for the quadruple and triple arrangement cases and at an interval of (8m×8m).

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

$$DU\% = \frac{\bar{R}_{lq}}{\bar{R}} * 100\% \quad .... (2)$$

where UC = Christensen uniformity coefficient, $\bar{R}$ =average depth of water reaching the ground (mm), R_i = depth of water reaching the ground in the grid cell (mm), DU = distribution uniformity coefficient, $\bar{R}_{lq}$ = average lower quartile depth (mm).

Tables (1-4) show the values of the uniformity coefficients and the distribution uniformity coefficients for the selected intervals in the case of operation at moderate, fast and slow rotation rates at a constant operating pressure head for the sprinkler heads (Weather tec 10-16, Rain bird 20A, SER, ATAK).

5. DISCUSSION OF RESULTS:

5.1. Single Sprinkler Water Distribution Pattern:

Effect of constant or cyclic variation operating pressure head: Figure (10) shows the water distribution pattern of a single sprinkler under constant pressure head and variable pressure head and for the four sprinkler heads (Weather tec 10-16, Rain bird 20A, SER, ATAK) at moderate sprinkler rotation speed. It is clear from the figure that there is almost complete agreement between the two water distribution patterns of a single sprinkler when using constant operating pressure head and cyclically variation operating pressure head. The figure shows the comparison at moderate sprinkler rotation speed, and this agreement is also present at slow sprinkler rotation speed and at fast sprinkler rotation speed.

Effect of sprinkler rotation speed: Figure (11) shows the water distribution pattern of a single sprinkler under constant pressure head and for different cases of sprinkler rotation speed and for all four sprinkler heads (Weather tec 10-16, Rain bird 20A, SER, ATAK). The figure shows a clear contrast between the water distribution patterns of a single sprinkler for different conditions of slow, moderate and fast rotation speed. When the sprinkler is operated at a fast rotation rate, the water distribution pattern creeps slightly towards the sprinkler so that the depth ratio increases with a decrease in the wetted area. When the sprinkler is operated at a slow rotation rate, the water distribution pattern creeps away from the sprinkler so that the depth ratio decreases with an increase in the wetted area.

5.2. Degree of Water Distribution Uniformity:

Effect of sprinkler rotation speed: From observing Tables 1-4, which include the values of the uniformity coefficient UC and the values of the distribution uniformity coefficient DU for a sprinkler operating at a constant pressure head and with different spacings in rectangular and triangular arrangements under the cases of moderate, slow and fast sprinkler head rotation speeds, and for the purpose of comparing these values in the case of decreasing or increasing the sprinkler rotation speed from what it is, i.e. comparing these values in the case of moderate rotation with slow rotation and comparing them in the case of moderate rotation with fast rotation, it appears from these tables that there is an increase in some cases and a decrease in others according to the spacings and arrangement of the sprinklers as well as the type of sprinkler. The maximum increase and decrease in the values of the uniformity coefficient UC and the values of the distribution uniformity coefficient DU can be determined as a result of changing the sprinkler rotation speed from moderate to slow and the maximum decrease as a result of changing the sprinkler rotation speed from moderate to fast from Tables (1-4), where the increase as a result of changing the sprinkler rotation speed from moderate to slow in the uniformity coefficient UC can reach 9.4% for the rectangular arrangement in the SER sprinkler at the spacing of 12 m × 20 m and 7.6% for the triangular arrangement in the SER sprinkler at the spacing of 12 m × 18 m and in the distribution uniformity coefficient DU to 21.2% for the rectangular arrangement in the SER sprinkler at the spacing of 10 m × 20 m and 15.2% for the triangular arrangement in the SER sprinkler at the spacing of 12 m × 12 m. Also, the decrease in the uniformity coefficient UC due to changing the sprinkler rotation speed from moderate to fast can reach 13.7% for the rectangular arrangement in the SER sprinkler at the spacing of 10m x 20m and 14.9% for the triangular arrangement in the SER sprinkler at the spacing of 16m x 20m and in the distribution uniformity coefficient DU can reach 20.8% for the rectangular arrangement in the Weather tec 10-16 sprinkler at the spacing of 12m x 16m and 16.3% for the triangular arrangement in the ATAK sprinkler at the spacing of 16m x 20m. Conversely, we can notice in the values of the uniformity coefficient UC and the values of the distribution uniformity coefficient DU in Tables (4-1), instead of increasing there is a decrease and instead of decreasing there is an increase, and as mentioned above, this depends on the spacings between the sprinklers, the arrangement of the sprinklers, and then the type of sprinkler.

Table (5) shows a comparison of the values of the uniformity coefficient and the distribution uniformity coefficient at slow, moderate and fast sprinkler head rotation speeds for the rectangular and triangular arrangements and the four sprinkler heads. The table shows the effect of the sprinkler rotation speed according to its type. First, with regard to the uniformity coefficient UC, the percentage of cases in which UC for slow rotation is greater than or equal to UC in the case of moderate rotation for the rectangular arrangement was the largest at the Weather tec 10-16 sprinkler head by 92.9% and as an average for all sprinklers 78.6%, and for the triangular arrangement it was the largest at the Weather tec 10-16 sprinkler head by 83.3% and as an average for all sprinklers 72.9%.

Table (1): Uniformity coefficient UC and distribution coefficient DU of a constant operating pressure head for different sprinkler spacings, rectangular and triangular arrangement, and different sprinkler head rotation speeds.

sprinkler head type Weather tec 10-16							
Distribution uniformity coefficient DU for different sprinkler head rotation speeds			Uniformity coefficient UC for different sprinkler head rotation speeds			Spacings and arrangement (S×L) m x m	
Fast rotation	Slow rotation	Moderate rotation	Fast rotation	Slow rotation	Moderate rotation		
94.0	96.48	98.7	94.4	95.5	95.4	6*6	Rectangular arrangement of sprinklers
93.0	79.9	92	95.9	96.1	95.4	6*10	
78.2	72.7	71.8	83.4	81.7	80.1	6*12	
70.4	68.7	67.2	85.2	84.3	83.6	8*8	
83.7	85.2	85.3	86.9	87.6	87.0	8*10	
68.4	67.1	65.0	87.0	86.6	85.2	8*12	
70.4	64.2	63.3	77.8	75.5	74.8	8*16	
84.5	84.4	83.0	87.1	90.0	87.0	10*10	
74.7	77.6	79.2	86.9	84.3	84.6	10*18	
60.8	73	69.3	76.8	83.9	81.8	10*20	
77.4	71.5	78.3	78.3	72	71.5	12*12	
64.4	61.6	81.3	81.3	79.7	78.6	12*16	
60.4	61.4	74	74	76.1	74.2	12*18	
59.2	62.7	67.7	67.7	73.7	69.5	12*20	
84	86.7	85.5	81.8	84.1	82.7	8*8	Triangular arrangement of sprinklers
73.9	77.1	74.5	82.7	84.8	83.0	8*10	
64.1	64.3	62.1	79.1	76.2	74.6	8*12	
62.5	59.8	58.3	76.4	74.8	74.1	8*14	
70.8	64.3	63.3	77.8	76.1	76.3	8*16	
68.4	69.6	62.6	77.7	77.3	74.0	12*12	
69.9	62.6	59.1	78	74.4	71.2	12*14	
63.7	57.9	54.5	78.6	77.8	76.7	12*16	
59.9	57.8	55.6	75.8	74.3	72.3	12*18	
68.8	53.8	54.7	65.7	58	57.7	16*16	
76.5	72.2	63.4	72.4	68.6	70.0	16*18	
61.2	65.2	58.7	71.8	72.9	71.7	16*20	

Table (2): Uniformity coefficient UC and distribution coefficient DU of a constant operating pressure head for different sprinkler spacings, rectangular and triangular arrangement, and different sprinkler head rotation speeds.

sprinkler head type Rain Bird 20A							
Distribution uniformity coefficient DU for different sprinkler head rotation speeds			Uniformity coefficient UC for different sprinkler head rotation speeds			Spacings and arrangement (S×L) m x m	
Fast rotation	Slow rotation	Moderate rotation	Fast rotation	Slow rotation	Moderate rotation		
91.9	91.5	90.6	92.8	92.4	91.6	6*6	Rectangular arrangement of sprinklers
90.6	89.1	89.7	93.1	91.7	92.1	6*10	
89.1	88.4	87.5	92.2	92.4	91.6	6*12	
79.2	83.8	83.4	89.6	91.9	91.7	8*8	
80.6	80	80	88.9	88	88.2	8*10	
86.9	88.1	88	94	93.8	93.8	8*12	
79.3	83.8	83.4	89.6	91.6	91.7	8*16	
88.4	82.9	84.2	90.1	87.3	88.7	10*10	
76.8	74.7	75.5	79.1	81.1	80.1	10*18	
69.7	77.2	75.3	74.4	79.7	79.3	10*20	
74	75.6	73.8	85.9	87.8	86.9	12*12	
80.8	79	78.2	84.5	85.9	85.5	12*16	
73.3	77.4	77.2	81.3	83.6	83.5	12*18	
63.9	73	71.5	74.6	83	83	12*20	
92	89.5	89.5	92.3	93.5	93.8	8*8	Triangular arrangement of sprinklers
89.5	88.4	89.1	92.2	91.7	91.8	8*10	
91.3	94.5	91.9	92.3	94.6	92.7	8*12	
87.4	87	86.6	91.4	89.2	87.7	8*14	
79	81.2	79.6	88.3	90.3	89.8	8*16	
87.3	86.4	84.9	89.9	89.1	88.4	12*12	
86.3	83.1	83.5	91.8	90.8	91.1	12*14	
76.8	77.4	76.4	84.6	87.5	87.2	12*16	
67.8	72.6	72.3	78.7	81.6	81.3	12*18	
72	67.5	70.9	79.5	81.2	81.5	16*16	
64.5	65.6	64.5	78.1	79.2	78.9	16*18	
67.4	66.7	66.3	72.5	77.7	77.3	16*20	

Table (3): Uniformity coefficient UC and distribution coefficient DU of a constant operating pressure head for different sprinkler spacings, rectangular and triangular arrangement, and different sprinkler head rotation speeds.

sprinkler head type ATAK						Spacings and arrangement (S×L) m x m	
Distribution uniformity coefficient DU for different sprinkler head rotation speeds			Uniformity coefficient UC for different sprinkler head rotation speeds				
Fast rotation	Slow rotation	Moderate rotation	Fast rotation	Slow rotation	Moderate rotation		
95.4	95	97.1	95.9	95.6	97.2	6*6	Rectangular arrangement of sprinklers
86.4	92	87.1	90	93.6	91.5	6*10	
72.6	72.9	69.1	79.8	79.9	78.5	6*12	
81.6	77.3	79.2	90.8	88.6	89.6	8*8	
79.3	82.7	81.5	89.6	89.7	90	8*10	
65.6	66.3	63	82.4	83.4	82.9	8*12	
72.1	66.1	67.5	83.2	79.8	80.3	8*16	
81.6	82.2	84.1	81.9	85.5	84.6	10*10	
76.7	81.2	79.4	86.4	87.6	87.7	10*18	
60.2	71.4	69.5	74.6	81.5	80.5	10*20	
62.9	66.1	62	74.4	73.1	71	12*12	
55.3	56.4	51.7	74.5	74.4	73.6	12*16	
59.4	59.8	58.8	73.5	76.1	73.9	12*18	
52	57.7	56.8	65.4	70	67.4	12*20	
87.7	87.1	88.2	86.3	86	86.2	8*8	Triangular arrangement of sprinklers
73.8	76.6	74.3	84.2	85.1	85	8*10	
65.1	65.1	63.1	76.4	76	75.1	8*12	
64.6	61.7	60.8	77.5	76.2	75.3	8*14	
72.1	66.1	67.5	83.4	81.2	81	8*16	
50.7	54.9	52.2	70.7	72.2	70.3	12*12	
52.2	54.4	51.5	67.5	68.5	67.8	12*14	
52.9	52.2	*	72.6	72.3	72.1	12*16	
62.1	60.2	57.4	74.2	75.1	73.4	12*18	
61.2	50.7	52.3	68.5	61.6	62.4	16*16	
66.7	59.1	61	76.4	73.7	74	16*18	
50.3	53	60.1	68.8	69.9	70.4	16*20	

Table (4): Uniformity coefficient UC and distribution coefficient DU of a constant operating pressure head for different sprinkler spacings, rectangular and triangular arrangement, and different sprinkler head rotation speeds.

sprinkler head type SER						Spacings and arrangement (S×L) m x m	
Distribution uniformity coefficient DU for different sprinkler head rotation speeds			Uniformity coefficient UC for different sprinkler head rotation speeds				
Fast rotation	Slow rotation	Moderate rotation	Fast rotation	Slow rotation	Moderate rotation		
91.7	97.7	93.8	92.6	98	94.5	6*6	Rectangular arrangement of sprinklers
91.2	91.8	88.5	93.8	93.9	91	6*10	
88.3	81.5	81.6	90.9	87	85.2	6*12	
96.7	91.4	92.2	95.6	95.7	96.1	8*8	
86.6	92.7	86	93.2	93.9	91	8*10	
85.6	80	79	92.6	90.2	89.6	8*12	
84.2	91.4	92.2	86.9	92.9	93.6	8*16	
87.3	86.1	86	89.1	88.4	86.8	10*10	
60.3	81.6	75.3	73.1	88.8	82	10*18	
*	62.3	51.4	61.8	77.6	71.6	10*20	
83	74.4	70.5	88.7	82.4	81.6	12*12	
77.2	77.1	73.1	82.3	86.8	83.3	12*16	
59.8	77.8	70.3	71.2	82.5	75.5	12*18	
*	62.9	51.2	61.6	73.4	67.1	12*20	
93.7	92.7	95.5	93.8	95	94.6	8*8	Triangular arrangement of sprinklers
86	88.3	84.5	93	94.1	90.9	8*10	
85.9	80.6	80.1	91.6	86.1	85.2	8*12	
91.7	85.4	85.5	93.2	87.5	89.6	8*14	
84.2	92.7	94.1	86.9	92.9	94.5	8*16	
73.5	70.2	60.9	84	81.4	76.8	12*12	
78.8	68.3	66.1	86.8	82.3	78.8	12*14	
76.1	72.8	70.3	82	84.8	80.5	12*16	
61.2	73.6	71	71.2	81.2	75.5	12*18	
78	78.7	84.6	84.4	82.9	86.6	16*16	
54.6	78.8	74.3	72.2	83.7	82.7	16*18	
*	*	*	60.2	75.1	70.7	16*20	

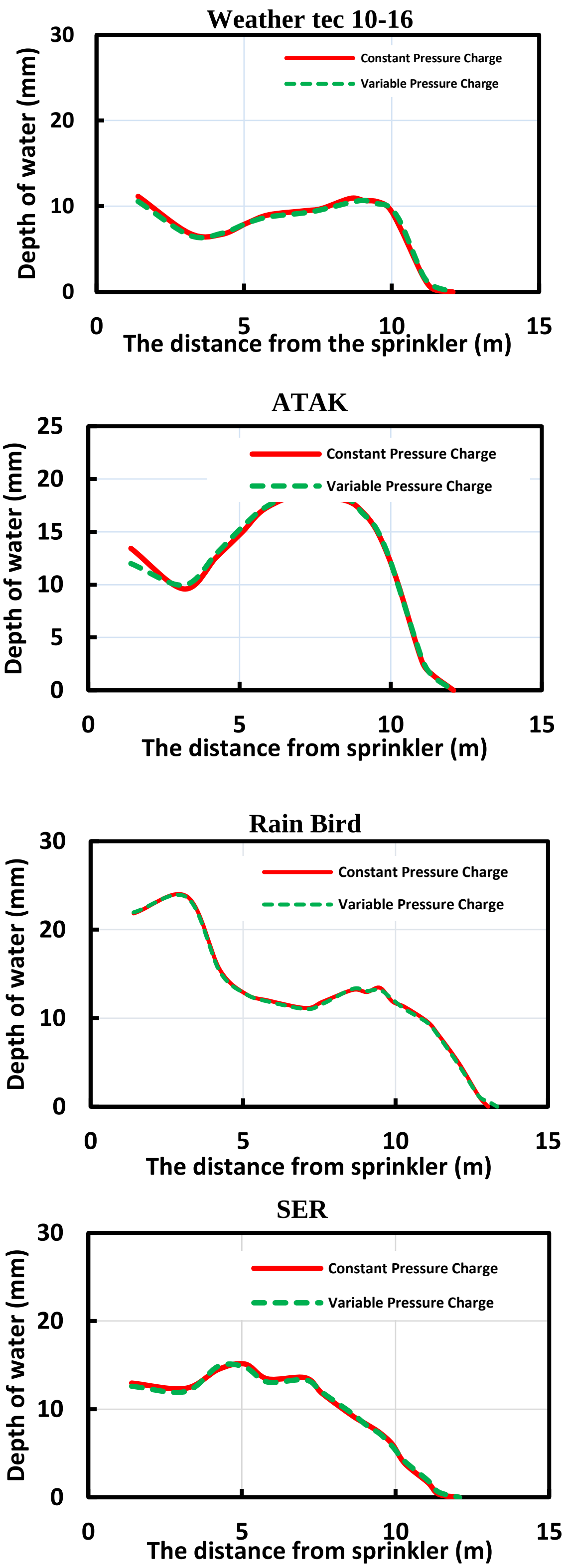

Figure (10): Water distribution pattern for a single sprinkler under constant pressure head and variable pressure head and for all sprinkler heads in this research.

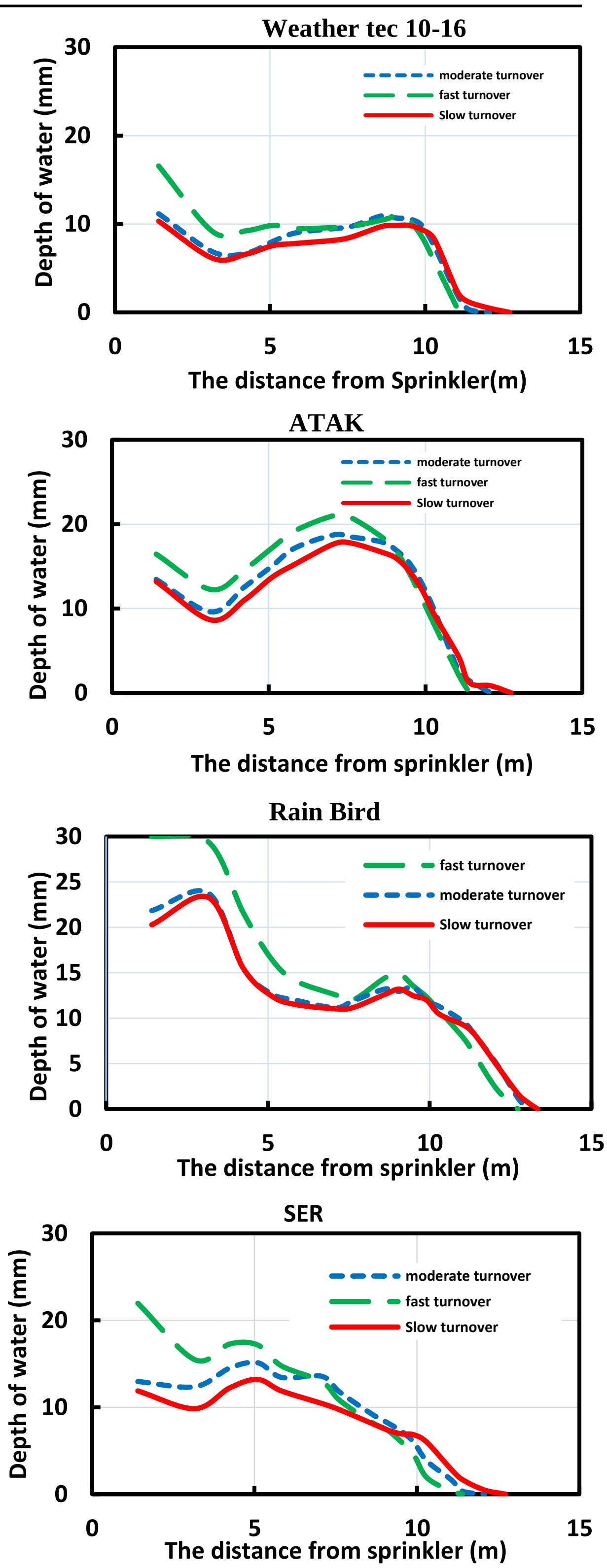

Figure (11): Water distribution pattern for a single sprinkler under constant pressure head and for different cases of sprinkler rotation speed and for all sprinkler heads in this research.

Table (5): Comparison of the uniformity coefficient and the distribution uniformity coefficient values at slow, moderate and fast sprinkler head rotation speeds for thfe rectangular and triangular arrangements and for the four sprinkler heads.

distribution uniformity coefficient DU		uniformity coefficient UC		Spray head type	Sprinklers arrangement
DU for fast rotation is less than or equal to DU for moderate rotation %	DU for slow rotation is greater than or equal to DU for moderate rotation %	UC for rapid rotation is less than or equal to UC for moderate rotation %	UC for slow rotation is greater than or equal to UC for moderate rotation %		
57.1	42.9	35.7	92.9	Weather tec 10-16	Sprinklers rectangular arrangement
42.9	78.6	57.1	71.4	Rain Bird 20A	
50.0	71.4	64.3	64.3	ATAK	
25.0	78.6	57.1	85.7	SER	
44.4	67.9	53.6	78.6	Total average for rectangular arrangement	
16.7	91.7	16.7	83.3	Weather tec 10-16	Sprinklers triangular arrangement
33.3	75.0	66.7	66.7	Rain Bird 20A	
33.3	54.5	25.0	66.7	ATAK	
41.7	58.3	50.0	75.0	SER	
31.3	70.2	39.6	72.9	Total average for triangular arrangement	
38.2	68.9	47.1	76.0	Overall average for all	

Secondly, for the uniformity coefficient UC, the percentage of cases in which the UC for fast rotation was less than or equal to the UC in the case of moderate rotation for the rectangular arrangement was the largest at the ATAK sprinkler head by 64.3% and as an average for all sprinklers 53.6%, and for the triangular arrangement it was the largest at the Rain Bird 20A sprinkler head by 66.7% and as an average for all sprinklers 39.6%. Thirdly, for the distribution uniformity coefficient DU, the percentage of cases in which the DU for slow rotation was greater than or equal to the DU in the case of moderate rotation for the rectangular arrangement was the largest at both the Rain Bird 20A and SER sprinkler heads by 78.6% and as an average for all sprinklers 67.9%, and for the triangular arrangement it was the largest at the Weather tec 10-16 sprinkler head by 91.7% and as an average for all sprinklers 70.2%. Fourthly, for the uniformity coefficient DU, The percentage of cases where the DU of fast rotation was less than or equal to the DU of moderate rotation for the rectangular arrangement was greatest at the Weather tec 10-16 sprinkler head at 57.1% and on average for all sprinklers at 44.4%, and for the triangular arrangement it was greatest at the SER sprinkler head at 41.7% and on average for all sprinklers at 31.3%. For the rectangular and triangular arrangements the average percentage of cases where the UC of slow rotation was greater than or equal to the UC of moderate rotation was 76.0%, the average percentage of cases where the UC of fast rotation was less than or equal to the UC of moderate rotation was 47.1%, the average percentage of cases where the DU of slow rotation was greater than or equal to the DU of moderate rotation was 68.9%, and the average percentage of cases where the DU of fast rotation was less than or equal to the DU of moderate rotation was 38.2%.

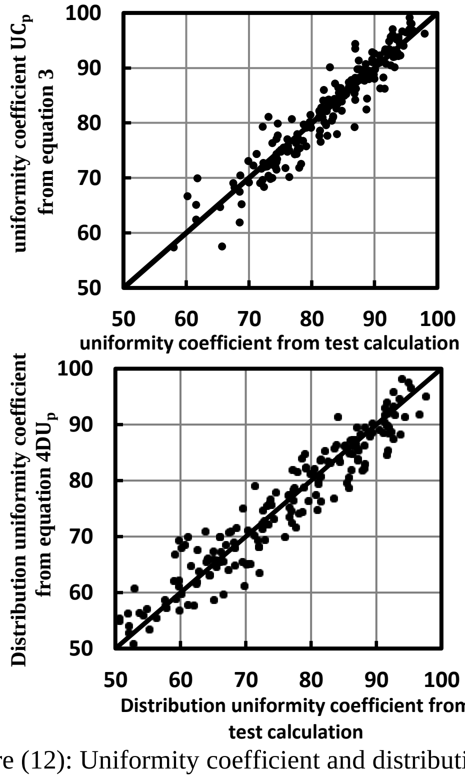

Figure (12): Uniformity coefficient and distribution uniformity coefficient Values calculated from the tests and from equations 3 & 4.

Estimating the degree of uniformity at a certain sprinkler rotation speed: Using the values of the uniformity coefficient UC and the distribution uniformity coefficient DU shown in Tables (1-4) and 208 values for each of the uniformity coefficient for the case of the fast and low sprinkler rotation rate UC_p, the uniformity coefficient for the case of the moderate sprinkler rotation rate UC_n, the distribution uniformity coefficient for the case of the fast and low sprinkler rotation rate DU_p, the distribution uniformity coefficient for the case of the moderate sprinkler rotation rate DU_n, the difference in the sprinkler rotation speed from the moderate sprinkler rotation ΔRPM, the ratio of the spacing between the sprinklers along the lateral pipe S to the spacing between the lateral pipes L, which is equal to S\L and is expressed by the spacing ratio SR, and the diameter of the smallest unit of the field distribution D which is equal to $[(S^2+L^2)^{0.5}]$, and with the help of the SPSS program, two equations were derived, the first to express the uniformity coefficient UC_p and the second to express the distribution uniformity coefficient DU, each of them as a function of each of UC_n, ΔRPM, SR, and D have coefficients of determination of 0.900 and 0.913, respectively, and the root mean square error (RMSE) value is 3.06 and 5.92, and the model efficiency (EF) value is 0.86 and 0.78, and the formulas are as follows: Equations 3 and 4:

$$UC_p = (0.058\times UC_n \times \Delta RPM - 5.343 \times \Delta RPM)\times SR + (1455.181\times \Delta RPM - 14.438\times UC_n)\times (D/100) \wedge 4.477 + 1.014 \times UC_n \quad (3)$$

$$DU_p = ((3.55\times \Delta RPM - 2.32\times DU_n)\times (D/100)\times 0.74 + (0.064\times \Delta RPM \times SR) + 0.79\times DU_n + 22.41) + (0.0213\times DU_n - 0.66))\times D \quad (4)$$

Figure (12) shows the values of the uniformity coefficient, and the distribution uniformity coefficient calculated from the equation and calculated from laboratory tests. **Effect of sprinkler arrangement**: Table (6) shows a comparison of the values of the uniformity coefficient UC and the distribution uniformity coefficient DU for the case of the rectangular and triangular arrangement of the sprinkler heads Weather tec 10-16, Rain bird 20A, SER, ATAK for cases of moderate, fast and slow rotation speed for common spacings between the two arrangements. (8m×8m), (8m×10m), (8m×12m), (8m×16m), (12m×12m), (12m×16m), (16m×16m). It is clear from the table that 77.4% of the uniformity coefficient values in the case of the rectangular arrangement are better than the uniformity coefficient values in the case of the triangular arrangement, and that 61.9% of the distribution uniformity coefficient values in the case of the rectangular arrangement are better than the distribution uniformity coefficient values in the case of the triangular arrangement

Table (6): Comparison of the values of the uniformity coefficient and the distribution uniformity coefficient for the case of the rectangular and triangular arrangement of the sprinkler heads under study and for the cases of different sprinkler rotation speeds for the common spacings (8m×8m), (8m×10m), (8m×12m), (8m×16m), (12m×12m), (12m×16m), (16m×16m).

Distribution uniformity coefficient DU		uniformity coefficient UC		Sprinkler head type
DU triangular arrangement is better than rectangular arrangement %	DU rectangular arrangement is better than triangular arrangement %	UC triangular arrangement is better than rectangular arrangement %	UC rectangular arrangement is better than triangular arrangement %	
23.8	**76.2**	**23.8**	**76.2**	**Weather Tec 10-16**
57.1	**42.9**	**38.0**	**61.9**	**Rain Bird 20A**
28.6	**71.4**	**19.0**	**81.0**	**ATAK**
42.9	**57.1**	**9.52**	**90.5**	**SER**
38.1	**61.9**	**22.6**	**77.4**	**All head types**

6. CONCLUSIONS:

1. There is no effect on the water distribution pattern when operating with a constant pressure head or with a cyclically variation pressure head at each level of the sprinkler rotation speed for all sprinkler heads under study.
2. The shape of the water distribution pattern creeps slightly into the sprinkler so that the depth ratio increases with a decrease in the wetted area when the sprinkler rotation speed increases and vice versa when the sprinkler rotation speed decreases.
3. The values of the uniformity coefficient UC and the distribution uniformity coefficient DU increase or decrease with the change in the sprinkler rotation speed and vary depending on the spacing between the sprinklers, the arrangement of the sprinklers, and then the type of sprinkler.
4. For the rectangular and triangular arrangements, the average percentage of cases in which the UC of slow rotation is greater than or equal to the UC of

moderate rotation is 76.0%, and the average percentage of cases in which the UC of fast rotation is less than or equal to the UC of moderate rotation is 47.1%.

5. For the rectangular and triangular arrangements, the average percentage of cases in which the DU of slow rotation is greater than or equal to the DU of moderate rotation is 68.9%, and the average percentage of cases in which the DU of fast rotation is less than or equal to the UC of moderate rotation is 38.2%.

6. The study provided estimated equations for both the uniformity coefficient UC or the distribution uniformity coefficient DU at different sprinkler rotation speeds depending on the uniformity coefficient UC or the distribution uniformity coefficient DU at moderate sprinkler rotation speed and the spacings between sprinklers.

7. That 77.4% of the uniformity coefficient UC values in the rectangular arrangement are better than the uniformity coefficient values in the triangular arrangement.

8. 61.9% of the values of the distribution uniformity coefficient (DU) in the case of the rectangular arrangement are better than the values of the distribution uniformity coefficient in the case of the triangular arrangement.

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تأثير سرعة دوران المرش وتغير شحنة الضغط دورياً على تناسق توزيع الماء للأنظمة الشبكية

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المستخلص:

تضمن البحث دراسة تأثير كل من سرعة دوران المرش وشحنة الضغط الدوري على نمط ودرجة تناسق توزيع الماء وتداخل ذلك مع الفواصل بين المرشات وترتيبها الرباعي والثلاثي لأربع رؤوس من المرشات المختلفة. شمل البحث إجراء فحوصات لإيجاد نمط توزيع الماء لمرشة مفردة على امتداد شعاع يمثل نصف قطر دائرة الابتلال مركزها المرشة ولشحنتي ضغط ثابتة ومتغيرة، وذلك عند معدلات دوران سريعة ومعتدلة وبطيئة لرؤوس المرشات. تم بعد ذلك إيجاد نمط التوزيع الحقلي لمياه الرش وبفواصل مختارة ومناسبة، وحساب درجة تناسق توزيع الماء بصيغة معامل التناسق ومعامل تناسق التوزيع. بينت النتائج انه ليس هنالك تأثير على نمط توزيع الماء وذلك عند التشغيل بشحنة الضغط الثابتة او التشغيل بشحنة الضغط المتغيرة دورياً عند كل من مستويات سرعة دوران المرشة، وذلك لكافة رؤوس المرشات قيد الدراسة، وإن معدل اعماق نمط توزيع الماء يزداد مع نقصان في المساحة المبتلة عند معدل الدوران السريع للمرش والعكس صحيح. قدمت الدراسة أيضا معادلات تخمينية لكل من معامل التناسق ومعامل تناسق التوزيع عند سرع مختلفة لدوران المرشة.

الكلمات الدالة:

أنظمة الرش الشبكية، معامل التناسق، سرعة دوران المرش، تغير شحنة الضغط، ترتيب المرشات