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Comparative Analysis of Some Commonly Used Impact Sprinklers Performances in the Different Wind Conditions and Sprinkler Arrangements

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Abstract

In this study the performances of some commonly used types of impact sprinklers were investigated in different wind speeds, sprinkler arrangements and spacing. Field experiments were conducted in different wind conditions for three types of sprinklers including IRRILINE 30, VYR 35 and RAINBIRD 40B and water distribution patterns of them were obtained. The distribution pattern of each single sprinkler was overlapped by setting of them in rectangular and triangular arrangements with spacing of 12×15, 12×18 and 15×18 m and also in square arrangement with spacing of 12×12, 15×15 and 18×18 m. Then the overall water application uniformity coefficients of each setting were calculated and compared with each other. In addition, in order to evaluate the two other impact sprinklers of RC 130H and VYR 70, Ador-Sprinkler simulating software was used and the performances of mentioned sprinklers were investigated at the same condition of experimental sprinklers. The results showed that the square arrangement of the field tested sprinklers with average uniformity coefficient of 74.45% had the maximum uniformity level and IRRILINE 30 showed the best performance among these sprinklers. According to simulating results of Ador-Sprinkler, the square arrangement for RC 130H and rectangular arrangement for VYR 70 could gain the maximum uniformity coefficients of 79.75% and 82.73%, respectively and the VYR 70 showed better performance in comparison with the other type of sprinkler. Generally the operations of VYR 35 and VYR 70 sprinklers were less affected by wind speed increment. According to the resulted relationships between the uniformity coefficient and wind speed, it can be stated that RC 130H was more sensitive to wind speed variation than VYR 70.

Keywords: Coefficient of Uniformity, Impact Sprinkler, Performance, Sprinklers Spacing and Arrangement, Wind Speed

INTRODUCTION

The sprinkler irrigation is known as one of the most common methods for agricultural lands irrigation. The operation of these systems has been increased due to their benefits. Accordingly, to address the issue of increasing the efficiency and improving the performance of sprinkler systems in various fields has been noticeable. Such a useful study in this regard is review of the performance of different sprinklers considering various arrangements and spacing and selection of the most appropriate sprinkler and arrangement for each regional wind speed conditions.

Several studies have been reported about comparing the performance of different types of sprinklers installed in the irrigation networks and choosing the best sprinklers and sprinkler arrangements. For selecting sprinkler spacing with an average water pressure in areas where winds are calm to moderate, to achieve a uniform distribution Keller and Bliesner [8] proposed that the sprinklers with square, triangular and rectangular arrangements would be located in spaces of 50 × 50, 62 × 62 and 67 × 40 percent of the effective wetted diameter respectively. They also expressed that sprinkle irrigation for areas with wind speed above 15 km/h was not recommended. Vories and Vonbernuth [14] studied the operation of single nozzle sprinklers on the fixed sprinkler irrigation systems in different wind conditions and distances of sprinklers in both triangular and rectangular patterns and simulated various combinations of nozzle size, pressure, spacing and arrangement of sprinklers at different wind speeds. The results showed that the triangular arrangement was not much better than the rectangular one and the optimal lateral positioning in a rectangular arrangement was placing it on the small side of this arrangement. Playan and et al. [11] studied the water distribution uniformity of two types of sprinklers using a ballistic model simulation. They used two kinds of sprinklers with two sizes of nozzle diameter at different operating pressures, wind speeds and sprinkler arrangements and eventually presented the results in a tabular form that was useful for design and management objectives in order to obtain desirable uniformity. An experiment was performed by Sheikhesmaeeli and et al. [13] to investigate the effects of arrangement and spacing of the three nozzles sprinklers on water distribution uniformity in the sprinkler irrigation systems. It was found that the maximum uniformity coefficient had been obtained with a square arrangement and to gain acceptable distribution uniformity at winds with speeds of more than 2 m/s, the maximum spacing of sprinklers would not be exceeded than 25 × 25 m. Moosavi and et al. [10] evaluated the effects of sprinkler irrigation system characteristics and meteorological parameters on the uniformity of water distribution and concluded that the pressure, nozzle diameter and wind speed had a meaningful effect on the uniformity coefficient. The square, equilateral triangle and rectangular arrangements showed the highest to the lowest uniformity, respectively. Bavi and et al. [3] discussed the influence of climatic and hydraulic factors on uniformity coefficient of water distribution in sprinkler irrigation in Omidiyeh area and concluded the decreasing of the uniformity coefficient was not significant with increasing wind speed up to 7 m/s, but in a wind speed higher than 7 m/s the coefficient of uniformity declined sharply. They also recommended that the ratio of Sprinkler spacing to wetting diameter should be reduced in high wind speeds and the square arrangement would be used. Moazed and et al. [9] investigated the effect of climatic and hydraulic parameters on water distribution uniformity coefficient in solid set systems. They analyzed the application uniformity of several sprinklers in different spacing and arrangements considering three wind speed ranges of lower than 5, 5 to 7 and higher than 7 m/s. In this study, the maximum (CU =91%) and the minimum (CU =80%) uniformity coefficient values were obtained for the square arrangements of 15 × 15 m and 21 × 21 m, respectively. Their recommendation to achieve to the desired uniformity of water distribution in wind speeds more than 7 m/s was reduction of sprinkler spacing and selection of square arrangement as possible.

Nowadays different types of sprinklers are used in sprinkler irrigation designs. Therefore investigation and comparison of the sprinklers performance in various conditions of wind, sprinklers layout and network dimensions in order to select the best operation of these systems appears to be necessary. In current study to analyze the water distribution uniformity in different Placement scenarios of adopted sprinklers, the uniformity coefficients were determined and compared with each other considering the actual wind speed values of the region during growth season. In addition, a water distribution pattern simulation model called Ador-Sprinkler was used to evaluate the uniformity of two common sprinklers considering wind conditions of the growing season.

MATERIALS AND METHODS

Statistical Information

In current study in order to consider the effects of wind speed over the next few years on the sprinkler distribution uniformity in Tabriz area, Seraj [12]'s research results were applied, in which the information of wind velocity were obtained from Tabriz Airport synoptic weather station located at 46◦ 17' E, 38◦ 05' N and 1361 m Altitude. After classification of wind speed data as the first, second and third decades of the growing months namely February to October, time series models had been fitted to the data and the wind speed values of the desired period had been predicted using the most appropriate time series models (Table 1). Distribution patterns of the single sprinklers related to each wind intensity were overlapped with each other considering the certain sprinkler spacing and arrangements then the overall uniformity coefficients were determined for each established system.

Table 1. Predicted wind speed using time series model

Month	Decade	Year		
		2013	2014	2015
		Average of daily wind speed (m/s)		
Feb	3	3.40	3.44	3.49
Mar	1	3.83	3.88	3.92
Mar	2	4.12	4.17	4.22
Mar	3	4.06	4.10	4.15
Apr	1	4.33	4.38	4.43
Apr	2	3.91	3.96	4.01
Apr	3	3.88	3.93	3.98
May	1	4.08	4.13	4.18
May	2	4.10	4.15	4.20
May	3	4.19	4.24	4.29
Jun	1	4.15	4.20	4.25
Jun	2	4.97	5.02	5.07
Jun	3	4.90	4.96	5.01
Jul	1	5.05	5.10	5.15
Jul	2	5.56	5.62	5.67
Jul	3	5.52	5.57	5.63
Aug	1	5.47	5.52	5.58
Aug	2	5.06	5.11	5.16
Aug	3	4.64	4.69	4.74
Sep	1	4.35	4.40	4.45
Sep	2	3.74	3.78	3.83
Sep	3	3.43	3.48	3.52
Oct	1	2.95	2.99	3.04
Oct	2	3.03	3.08	3.12

Field Experiments

To determine the effect of wind on sprinkler systems during the growth season, the data of experimental distribution patterns that had been provided by Bazzaneh [4] and the simulated patterns of Ador-Sprinkler model were applied. The experiments of the single sprinklers distribution patterns had been conducted in research station areas related to the Agricultural Faculty of the Tabriz University located at 38^0 1' N latitude and 46^0 3' E longitude and altitude of 1557 m above sea level. The features and conditions of the mentioned tests are briefly as follows: A network of water catch containers had been placed on the ground at intervals of 1 m from each other and three impact sprinklers had been used with brand names of IRRILINE 30, VYR 35 and RAINBIRD 40B and

4/4 × 2/4 mm nozzles sizes. It should be noted, all the applied procedures were in compliance with the criteria set forth in the ASAE 330.1 [1] and ISO 8026 [2] standards. To evaluate the effect of wind velocity on the performance of each sprinkler, three wind speed ranges of 0 to 2, 2 to 4 and more than 4 m/s were considered based on the recommendation of Keller and Bliesner [8]. In this research, arrangements of rectangular and triangular with 12 × 15, 12 × 18 and 15 × 18 m dimensions and square arrangement with 12 × 12, 15 × 15 and 18 × 18 m spacing were used (For more information refer to Bazzaneh [4]).

Simulation the Effect of Wind on the Distribution Pattern

In addition to the experiments, the distribution patterns of two other sprinklers (RC 130 H and VYR 70) were simulated in different arrangements and regional wind speeds using Ador-Sprinkler software. The Ador-Sprinkler program was presented by Dechmi and et al. [6, 7] with the aim of simulating the performance of sprinkler irrigation systems. In this model the ballistic method was utilized to simulate the water distribution pattern of sprinklers. To use of this program, the combinational information of the meteorological data, including wind speed and direction are needed as well as the operational data such as arrangement of sprinklers, operating pressure, nozzle height and irrigation time. The operating pressure applied in simulations were considered approximately equal to the experimental pressure of 300 kPa and the nozzles diameters were 4/4 × 2/4 mm. The predicted wind speed values from the time series model were used as the model input data and the required prevailing wind direction data were obtained from wind rose plot application of WRPLOT View. In the present study the lateral direction were considered along the prevailing wind in the growing season. So, considering the aforementioned sprinklers arrangements, totally 9 output data sets for each sprinkler were got to calculate the Christiansen uniformity coefficient (CUC) [5] in different wind conditions. The Christiansen uniformity coefficient has been defined as follows:

$$CUC(\%) = \left(1 - \frac{\sum_{i=1}^{n}|x_i - \bar{x}|}{n\bar{x}}\right) \times 100 \qquad (1)$$

Where, CUC is Christiansen uniformity coefficient (%), x_i is water depth in each catch can (mm), $\bar{x}$ is average of water depths within the cans (mm) and n is total number of containers.

RESULTS AND DISCUSSION

Results from Experiments

The average uniformity coefficient of water distribution in the growing season was obtained for each position of the sprinklers, as shown in Figure 1. This graph shows that the uniformity coefficients of the sprinklers closer to each other are higher in comparison with the sprinkler having larger distances, due to better overlapping. According to the results, for achieving to the uniformity coefficient more than 75% in the assumed arrangements, the maximum spacing of sprinklers is recommended as described in Table 2.

According to Table 2, in wind speeds above 4 m/s for achieving to the distribution uniformity of more than 75% with square arrangement of the sprinkler VYR 35, the spacing between the sprinklers should not be exceeded than 12 × 12 m. While considering the same condition for a rectangular arrangement, the sprinklers spacing should not be exceeded than 12 × 15 m.

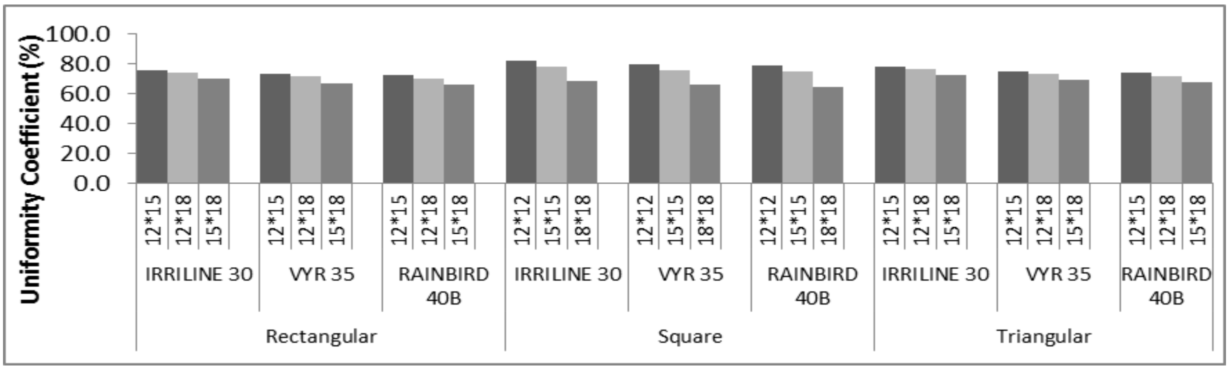

Figure 1. Average uniformity coefficient for each position of the experimental sprinklers

Table 2. Maximum sprinkler spacing (m×m) to achieve uniformity coefficient more than 75% in the growing season

Wind Speed (m/s)	Sprinkler								
	IRRILINE 30			VYR 35			RAINBIRD 40B		
	Rec	Squ	Tri	Rec	Squ	Tri	Rec	Squ	Tri
0-2	-	-	-	-	-	-	-	-	-
2-4	12×18	15×15	15×18	12×18	15×15	12×18	12×15	15×15	**12×18**
>4	<12×15	15×15	12×15	<12×15	12×12	<12×15	<12×15	12×12	**<12×15**

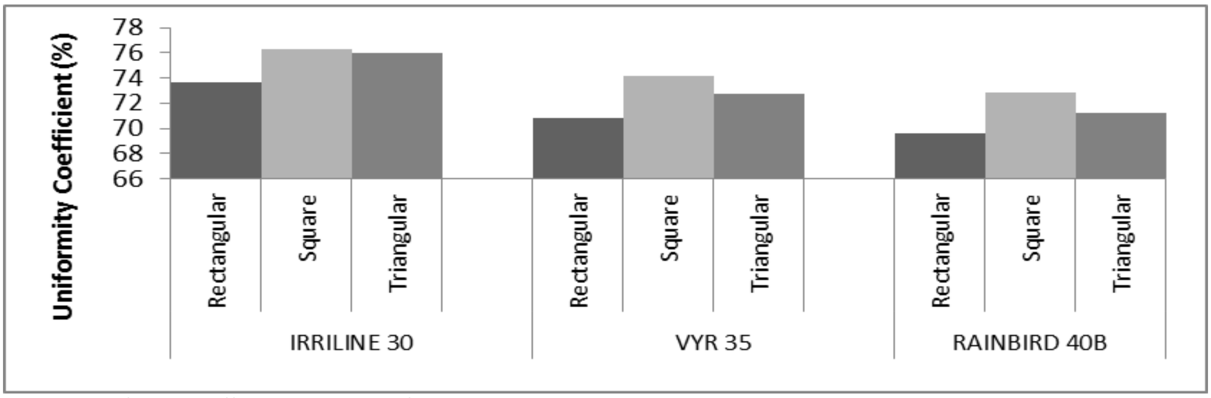

Figure 2. Uniformity coefficient comparison of the experimental sprinklers

In order to compare the uniformity coefficient of sprinklers in assumed arrangements Figure 2 is depicted. According to this graph, the advantage of square arrangement for all types of sprinklers can be realized than others. After square arrangement, triangular arrangement has shown better performance in aspect of uniform distribution of water. In whole arrangements the uniformity coefficient of sprinkler IRRILINE 30 is more than CUC of the other two sprinklers.

Results from Ador-Sprinkler Simulation Model

Evaluating the sprinklers used in the simulation model of Ador-Sprinkler as shown in Figure 3, it's realized that the uniformity coefficient of closer sprinklers are higher in comparison with larger distances due to better overlap. To achieve uniformity coefficient more than 75% in the assumed arrangements, the maximum spacing of these sprinklers is recommended as described in Table 3.

According to Table 3, if the wind speed is above 4 m/s and sprinkler VYR 70 with rectangular arrangement is considered for irrigation system design, to achieve at least 75% uniformity of water distribution, the spacing between sprinklers is not recommended more than 12 × 18 m.

In order to compare the uniformity coefficient of sprinklers in the assumed arrangements Figure 4 is depicted. According to this graph, the RC 130H sprinkler with square arrangement and VYR 70 sprinkler with rectangular layout has shown better performance and generally the VYR 70 distribute water more uniform than the RC 130H.

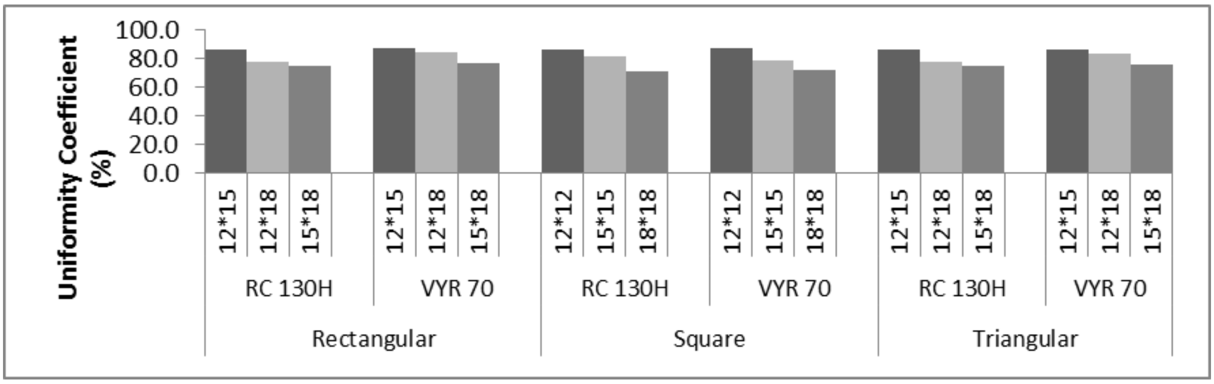

Figure 3. Average uniformity coefficient for each position of the sprinklers applied in simulation

Table 3. Maximum sprinkler spacing (m×m) to achieve uniformity coefficient more than 75% in the growing season

Wind Speed (m/s)	**Sprinkler**					
	RC 130H			**VYR 70**		
	Rec	**Squ**	**Tri**	**Rec**	**Squ**	**Tri**
0-2	-	-	-	-	-	-
2-4	15×18	18×18	15×18	15×18	18×18	**15×18**
>4	12×15	15×15	12×15	12×18	15×15	**12×18**

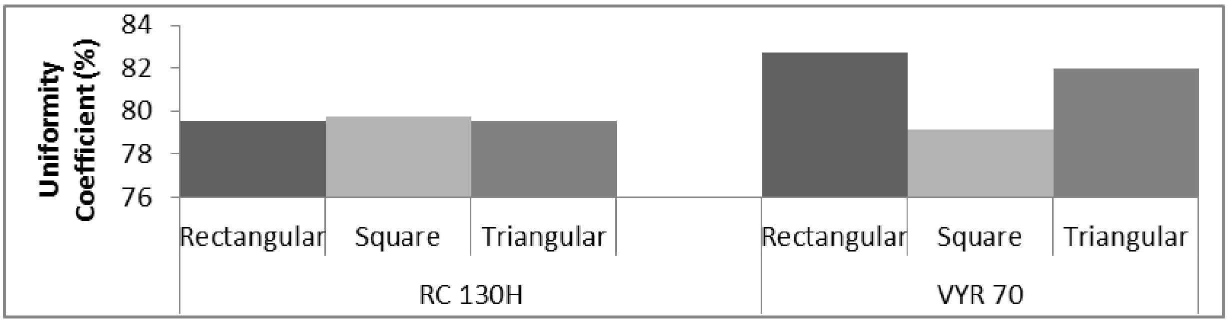

Figure 4. Uniformity coefficient comparison of the sprinklers applied in simulation

To gain an insight about relationship between the wind velocity and the Christiansen uniformity coefficient for various arrangements of RC 130H and VYR 70 sprinklers Figures 5 and 6 were depicted respectively.

The linear model due to its easier usage was fitted to data for the different states of sprinkler spacing and layouts. It can be received from both figures that application uniformity reduces when the sprinklers get farther away from each other at entire arrangements and the slope of lines becomes steeper with increasing of sprinklers distances. In other words, adding the amount of wind speed equal to unit value (1 m/s), the reduction of uniformity coefficient in greater distances is more obvious than smaller distances. But it should be noted that the mentioned reduction is more evident in the sprinkler RC 130H than the sprinkler VYR 70 which means that RC 130H sprinkler is more sensitive to wind speed changes than VYR 70.

The fitted linear equations between wind speed and uniformity coefficient in various arrangements of sprinklers are provided in Table 4. According to these equations, it can be clearly observed that the wind speed coefficient or in other words slope factor becomes greater with increasing of the sprinklers spacing. The obtained R2 coefficients in all models show high correlation between wind velocity and uniformity coefficient and confirm the suitability of the linear model.

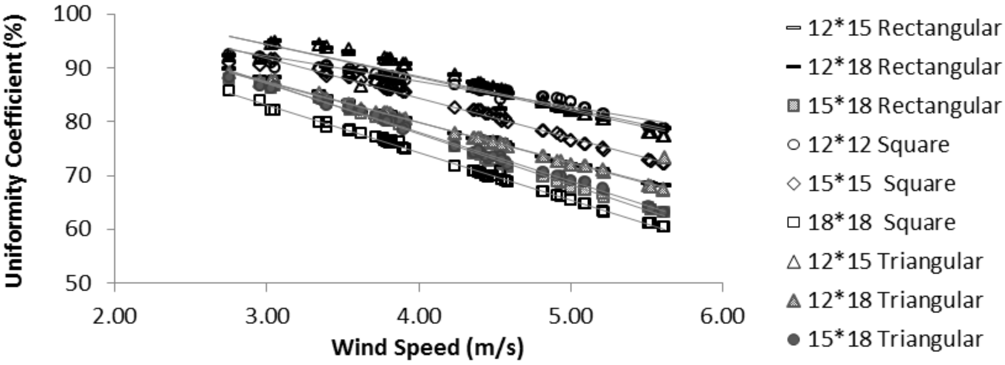

Figure 5. The relationship between wind speed and uniformity coefficient of RC 130H sprinkler

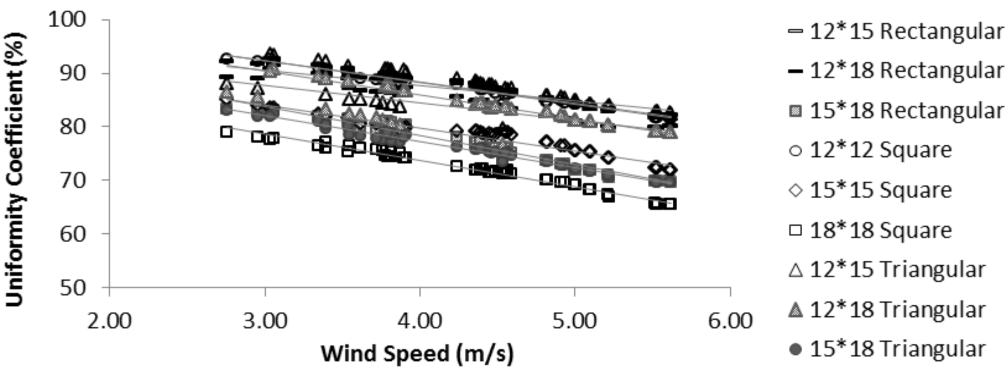

Figure 6. The relationship between wind speed and uniformity coefficient of VYR 70 sprinkler

Table 4. The fitted models to data for sprinklers applied in simulation

Arrangement	Spacing (m×m)	Model	
		RC 130H	VYR 70
Rectangular	12×15	CU= -3.2162W+100 $R^2 = 0.7162$	CU= -3.0079W+100 $R^2 = 0.8256$
	12×18	CU= -5.2996W+100 $R^2 = 0.9022$	CU= -3.6029W+100 $R^2 = 0.8350$
	15×18	CU= -5.9552W+100 $R^2 = 0.8530$	CU= -5.4139W+100 $R^2 = 0.9648$
Square	12×12	CU= -3.2984W+100 $R^2 = 0.8703$	CU= -3.0571W+100 $R^2 = 0.9162$
	15×15	CU= -4.2719W+100 $R^2 = 0.8022$	CU= -4.9776W+100 $R^2 = 0.9227$
	18×18	CU= -6.6809W+100 $R^2 = 0.9362$	CU= -6.3970W+100 $R^2 = 0.8837$
Triangular	12×15	CU= -3.2754W+100 $R^2 = 0.6952$	CU= -3.0486W+100 $R^2 = 0.4659$
	12×18	CU= -5.2963W+100 $R^2 = 0.8967$	CU= -3.8077W+100 $R^2 = 0.5460$
	15×18	CU= -5.8710W+100 $R^2 = 0.8700$	CU= -5.5981W+100 $R^2 = 0.9594$

CONCLUSION

In order to evaluate and compare the effect of wind on impact sprinklers performance, three sprinklers of IRRILINE 30, VYR 35 and RAINBIRD 40B were chosen and overall uniformity coefficient of water distribution was determined via making overlap between distribution patterns of single sprinklers in various conditions of wind, arrangement and spacing of sprinklers. The results showed that the square arrangement using the three types of sprinkler could create the highest uniformity with average value of 74.45%. Also the sprinkler of IRRILINE 30 showed the best performance compared to other sprinklers. The sprinkler VYR 35 showed the minimal reduction of uniformity versus increase of wind speed.

In addition to the experiments, Ador-Sprinkler software was used to simulate the distribution patterns of two other sprinklers (RC 130 H and VYR 70) in wind speed condition of Tabriz region. The advantage of this software was that the actual wind speed could be imported to model instead of considering wind speed classes and the simulation could be run on the exact value of wind velocity. The results showed that the RC 130H sprinkler with square arrangement and VYR 70 sprinkler with rectangular layout could make the highest uniformity coefficient with amount of 79.75% and 82.73% respectively. In general, the VYR 70 distributed water more uniform than the RC 130H. The sprinkler VYR 70 showed the most appropriate performance due to minimal reduction of uniformity versus increase of wind speed.

The linear model was fitted between the wind velocity and the Christiansen uniformity coefficient for various setting of RC 130H and VYR 70 sprinklers. It could be concluded that RC 130H sprinkler is more sensitive to wind speed changes than VYR 70.

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