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# Effects of Climatic and Hydraulic Parameters on Water Uniformity Coefficient in Solid Set Systems

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**Abstract:** In order to study the effects of different wind conditions, operating pressures, various sprinklers layouts and spacing on water distribution uniformity in sprinkler irrigation system a research project was conducted under 3 different wind velocities (0-5, 5-7 and > 7 m sec$^{-1}$), using 3 operating pressure (35, 40 and 45 m), three spacing on the lateral pipeline (15, 18 and 21 m) and 3 different layouts (square, rectangular and triangular). Simulation experiments were conducted to estimate water distribution uniformity. The results indicated that the distribution coefficient uniformity decreased with the increase of the wind velocity. With the increase of wind velocity up to 7 m sec$^{-1}$, the decrease of coefficient uniformity was not significant (the coefficient was reduced by 20% in the range of wind velocity applied). The highest water distribution coefficient uniformity was occurred on 15×5 m spacing while the lowest value was achieved for spacing of 21×21 m and sprinkler spacing to spray diameter of 0.5×0.5 with the increase of sprinklers spacing to the spray diameter, coefficient uniformity is reduced, especially at higher wind velocities. Therefore at higher wind velocities, it is recommended to reduce sprinklers spacing to spray diameter ratio and use square arrangement in order to achieve acceptable uniformity.

**Key words:** Sprinklers layout, sprinklers spacing, sprinkler irrigation, wind conditions, dispersion range

## INTRODUCTION

In the course of development of irrigation technology, a broad range of solutions has been applied to improve irrigation processes from the technical, organizational and economic point of view. Since, 1970 industrialized nations have focused on reduction of irrigation labor requirements and elimination of unacceptable working conditions, goals that, as a general rule, can be achieved through investment in modern irrigation equipment. Introduction of sprinkler irrigation machines around 1950 and relevant developments in the 1960s and 1970s, represented a decisive technological step, as did replacement of sprinkler booms by portable aluminum pipe sprinkler irrigation systems, which provided an 80% reduction in labor requirements (De Boer and Chu, 2001). One of the most relevant parameters in sprinkler irrigation systems is the uniformity of water distribution (Merriam and Keller, 1978). Field irrigation evaluations are used to establish irrigation performance, which for sprinkler irrigation is primarily represented by irrigation uniformity. During the evaluation process, quantitative levels of uniformity are established. Sprinkler irrigation systems require a minimum value of uniformity to be considered acceptable. For solid set sprinkler systems, Bliesner and Keller (2001) classified irrigation uniformity as low when the Christiansen Coefficient of Uniformity (CU) is below 84%. Little *et al*. (1993) reported that SCS classifies uniformity of a sprinkler irrigation system as very good, good, poor and worst if the Christensen Uniformity Coefficient (CUC) value is = 90%, between 80 and 89%, between 70 and 79% and > 69%, respectively. Tari (1998) reported CUC and distribution uniformity (DUlq) values between 58 and 82% and between 37 and 82%, respectively, in the Konya-Ilgýn Plain, Turkey.

In all types of mobile irrigation machines, the characteristics of the spray plate sprinklers, overlapping spacing and machine speed determine irrigation performance. The precipitation rate (mm h$^{-1}$) is a key factor in the evaluation of irrigation performance. When the precipitation rate is higher than the soil infiltration rate, water remains on the soil surface and runoff can occur, so that to obtain an adequate performance, the precipitation rate of the machine must be as high as possible but always lower than the soil infiltration rate (Bliesner and Keller, 2001; De Boer and Chu, 2001). De Boer (2002), using a catch-can spacing of 0.25 m,

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found that the wetted radius of an R 3000 D-4 tended to increase with an increase in nozzle pressure and nozzle diameter; this narrower catch-can spacing resulted in more accurate estimations of the wetted radius. Several authors have reported that wind is the main environmental factor affecting sprinkler performance (Dechmi *et al*., 2003a). Since, most fields are smaller than 10 ha, solid set irrigation is the most common technical solution. Although triangular sprinkler spacings of 21×18 m were common 10 years ago (Dechmi *et al*., 2003b), nowadays the most frequently used spacings are triangular 18 ×15 m and 18×18 m. Performance Assessment (PA) of irrigation and drainage systems has been an important area of research and debate within the irrigation community in recent years (Vincent *et al*., 2001). This is recognized as the systematic observation, documentation and interpretation of the management of an irrigation system (Bos *et al*., 2005). Martinez *et al*. (2004) analyzed the influence of different design and performance factors, such as subunit arrangement, lateral spacing, working pressure, average application rate and application efficiency of water application cost, in a permanent set sprinkler irrigation system. The results showed that the most important factor is sprinkler spacing. As emphasized by Frizzone *et al*. (2007), the uniformity of moisture from the soil and the productivity of irrigated crops are very dependent on uniformity of water applied during the irrigation. To assess the effect of various factors on uniformity of application of conventional water spray systems, equipped with hydraulic cannons, Azevedo *et al*. (2000) noted that the wind speed was the factor which most influenced in uniformity of application of water, followed by the pressure of the sprinkler, spacing between sprinkler installations in the lateral line, line spacing, wind direction towards lateral line and speed of rotation of the sprinkler. The objective of the present research was to study the effects of different wind conditions, operating pressures, various sprinklers layouts and spacing on water distribution uniformity in sprinkler irrigation system, in Khuzestan province, South West of Iran.

## MATERIALS AND METHODS

The studies described in this research were conducted on an oat-stubble field at the research farmland, located southeast Khuzestan province of Iran at 49° 42’ 30’’ E and 30° 50’ N with a net area of 42 ha during the period of March (2008) through February (2009). Irrigation water for the farmland is supplied from Zoreh River which is 12 km away from this pilot site. The commercial (jaleh model 3) with two nozzles (7.32"×3.32")

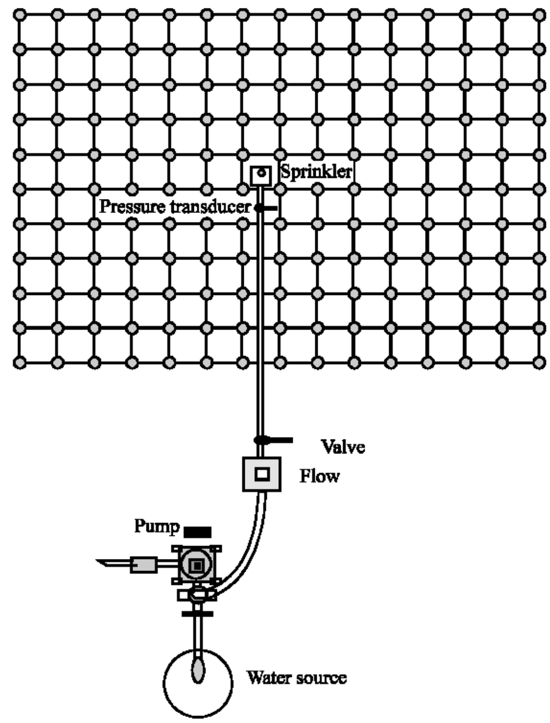


Fig. 1: Arrangement of rain gauges (catch-containers) around the sprinkler

impact sprinkler was located on the lateral. Riser allowed the sprinkler to be placed 1.75 cm above the catch- can openings. The system was operated at three pressure levels of 35, 40 and 45 m. A total of 100 catch containers on a 3×3 m grid system were located on both side of the lateral around the sprinkler (Fig. 1) shows an arrangement of rain gages for such a test. The area around the sprinkler was divided into squares of equal area. A catch-can placed at the center of each square then represented the precipitation falling on that area and the catch-cans opening diameter was 10 and 15 cm height. The measurable parameters in this study included: wind velocity, operating pressure, flow discharge and volume of water from the sprinklers accumulated in the containers. The sprinkler’s flow discharge was accurately determined by using a volume meter and a chronometer. Omidieh region is a windy area with the different wind velocities during a season three wind velocities were occurred during the time of March 2008 through February 2009. through this period of time different wind velocities were occurred and by each wind velocity some experiments were conducted, for example when the wind velocity was under 5 km sec$^{-1}$ (0-5 m sec$^{-1}$) we conducted some experiments and while it was between (5 and 7 m sec$^{-1}$), or upper than 7 m sec$^{-1}$ some other experiments were conducted. Wind velocity and direction at 2 m above ground were measured with a recording three-cup anemometer and wind vane for a time period equal to the duration of a test, which was about 1 h. The present study is carried out during the period of March (2008) through February (2009). In order to obtain logic and reliable results 75 tests were carried out in different hours overnight, so the correlations and diagrams would represent a wide range of hydraulic and climatic conditions. Software SPSS version 14 were used for statistical analysis. Christiansen Equation (Eq. 1) was utilized to determine CU.

$$CU = 100\left(1 - \frac{\sum_{i=1}^{N}\left|y_i - \bar{y}\right|}{\sum_{i=1}^{N} y_i}\right) \quad (1)$$

where, CU is Christiansen Coefficient Uniformity, $y_i$ is water contained in catch-cans, $\bar{y}$ is average of water sprayed on cans and N is the number tests.

## RESULTS AND DISCUSSION

In order to study the effects of different wind conditions, operating pressures, various sprinklers layouts and spacing on water distribution uniformity in sprinkler irrigation system a research project was conducted under 3 different wind velocities (0-5, 5-7 and > 7 m $sec^{-1}$), using 3 operating pressure (35, 40 and 45 m), three spacing on the lateral pipeline (15, 18 and 21 m) and 3 different layouts (square, rectangular and triangular). Table 1 shows the effect of various operating pressures on uniformity coefficient of sprinkler. As seen from Table 1, when the operating pressure moves from 35 to 40 m (an increase of 14%), the coefficient rises for 6.2%. One can infer that the relation here is not linear and with lower pressures, the slope is steeper. Based on Keller (1983) study, in a given sprinkler as the operating pressure lowers, the dispersion is intensified and water drops hit the ground with greater effect but this will decrease the water distribution uniformity, therefore, he suggested that the lower operating pressure occurs when sprinklers spacing is lower. He also concluded that the most effective factor in reducing coefficient uniformity in low operating pressure condition is the relatively excessive sprinkled water in the predefined dispersion range. Pressure enhancement will decrease excessive sprinkled water within due range of water dispersion leading to an improved water distribution uniformity coefficient. If the given sprinkler has a pressure of 40 to 50 m, the coefficient will reach beyond 80%, which is acceptable to almost all the designers and manufacturers. Keller (1983) study also did not recommend an operating pressure more than 45 m and the results agree with those of similar researches about moderate and high pressures. It is suggested that in order to specify the optimum amount of operating pressure a wider range of pressures is tested.

Table 1: Water dispersion coefficient uniformity in various operating pressures

| Pressure (m) | Uniformity coefficient (%) | Pressure increase (%) to pressure (35 m) | Coefficient increase (%) to pressure (35 m) |
|---|---|---|---|
| 35 | 81 | | |
| 40 | 86 | 14 | 6.5 |
| 45 | 88 | 26 | 7.9 |

Table 2: Effect of different sprinklers layouts on water dispersion coefficient uniformity

| Sprinklers layouts | Coefficient uniformity (%) |
|---|---|
| Rectangular | 82 |
| Triangular | 85 |
| Square | 86 |

**Effects of sprinkler layouts on water dispersion uniformity coefficient:** As it can be seen in Table 2, the square layout enjoys the higher water dispersion uniformity and the rectangular layout has the lowest coefficient. Although, this coefficient for triangular arrangement is higher than that of rectangular arrangement, due to persisting operational problems such as displacement of the pipelines in the semi-movable system, this configuration is not used in this system, however, in solid-set systems it is used with better efficiency and higher uniformity coefficient. One of the decisive factors in raising the coefficient uniformity is the extent of overlapping of the sprinklers. Overlapping in square layouts are almost the same in all directions while in a rectangular arrangement they differ in latitudinal and longitudinal directions. Tarjuelo *et al.* (1994) investigated this issue in their studies and concluded that square arrangements, in comparison to rectangular arrangements, have a higher uniformity coefficient. It should be noted that the findings of the present study backed up the results of Tarjeulo's studies suggesting that to the possible extent square and equilateral arrangements (where sprinklers spacing on the lateral pipes and the spacing of lateral pipes on the main pipes are equal) be used. To find optimal pressure, it is recommended to investigate more operating pressure on distribution uniformity. Martinez *et al.* (2004) analyzed the influence of different design and performance factors, such as subunit arrangement, lateral spacing, working pressure, average application rate and application efficiency of water application cost, in a permanent set sprinkler irrigation system. The results showed that the most important factor is sprinkler spacing.

Table 3: Coefficient effects of sprinklers spacing on water distribution uniformity

| | Spacing (m) | | | | | |
|---|---|---|---|---|---|---|
| Parameters | 15 × 18 | 15 × 21 | 18 × 21 | 15 × 15 | 18 × 18 | 21 × 21 |
| Spacing to dispersion range (36 m) | 0.42×0.50 | 0.42×0.58 | 0.50×0.58 | 0.42×0.42 | 0.50×0.58 | 0.50×0.50 |
| Spacing to dispersion range (37 m) | 0.40×0.48 | 0.40×0.57 | 0.48×0.57 | 0.40×0.40 | 0.48×0.48 | 0.57×0.57 |
| Spacing to dispersion range (38 m) | 0.39×0.47 | 0.39×0.55 | 0.47×0.55 | 0.39×0.39 | 0.47×0.47 | 0.55×0.55 |
| Coefficient uniformity (%) | 84 | 82 | 81 | 91 | 87 | 80 |
| Increase of uniformity coefficient to maximum spacing (21×21 m) | 5 | 2.5 | 1.25 | 13.8 | 8.7 | 0 |

Table 4: The effects of wind velocity on water uniformity distribution coefficient

| Wind velocity (m sec$^{-1}$) | Uniformity (%) | Reduction (%) |
|---|---|---|
| 0-5 | 90 | ---- |
| 5-7 | 88 | 2.3 |
| >7 | 75 | 20 |

**Effects of sprinklers spacing on water distribution uniformity coefficient:** As it mentioned in Table 3, the highest coefficient uniformity was obtained in 15×15 m spacing while the lowest amount was gained in 21×21 m arrangements. In general, one can conclude that by increase of the sprinklers' spacing the coefficient uniformity reduces. The main reason can be relegated to greater overlapping of the sprinklers at shorter intervals. In order to better determine this, the relation of the sprinklers' spacing to the distribution uniformity range was calculated and different spacing's were plotted for coefficient uniformity (Table 4). The results showed that by lowering the spacing of the sprinklers installed on lateral pipes a reducing the relation of intervals to dispersion range, coefficient uniformity increased. After studying various arrangements, proposed several optimum spacing: for square and rectangular arrangements the optimum spacing of the sprinklers to the dispersion diameter should be respectively 0.4×0.6 and 0.5. Keller (1983) also suggested a general rule for arrears with moderate wind condition. According to him, for square, rectangular and triangular arrangements the relation of spacing to the dispersion range should be respectively 0.5, 0.4x0.67 and 0.62 at best. For low wind speed (up to 6.4 km h$^{-1}$) the spacing between sprinklers should be equal to 60% of diameter of normal spray, for medium wind speed (6.4 to 12.8 km h$^{-1}$) spacing should be equal to 50% of diameter of normal spray and for high wind speed (above 12.8 km h$^{-1}$) the spacing should be equal to 30% of the diameter of normal spray (Shanmugam, 1990). The present study emphasized the fact that if the above spacings are applied, coefficient uniformity will rise to approximately 80%, which is confirmed by almost the designers and manufacturers of irrigation systems. The results agree with those by Keller (1983) researches. Cuenca (1989) also reported that CUC values generally can increase when lateral spacing decreases, but results in increased capital costs. Vories and Von Bernuth (1986) claimed that reducing sprinkler irrigation lateral and sprinkler head spacing increases CUC.

**Effects of wind velocity on uniformity coefficient:** According to Table 4 as a result of wind speed increase the coefficient uniformity decreased in all parameters (sprinklers layouts, operating pressures, etc.). Several authors have reported that wind is the main environmental factor affecting sprinkler performance (Seginer *et al*., 1991; Faci and Bercero, 1991; Tarjuelo *et al*., 1994; Kincaid *et al*., 1996; Dechmi *et al*., 2003b). These references have led to two firm conclusions. First, applied water is lost partially by evaporation, particularly through drift out of the irrigated area second, under windy conditions, the water distribution pattern of an isolated sprinkler is distorted and narrowed. Therefore, the CU generally shows a tendency to decrease as wind speed increases. Since, it was not possible to compare the results of different parameters at a steady wind velocity, the comparisons were made using three different wind conditions, low (0-5 m sec$^{-1}$), moderate (5-7 m sec$^{-1}$) and high (>7 m sec$^{-1}$) winds. In moderate wind condition (5-7 m sec$^{-1}$), the coefficient was reduced by 2.2% compared to low wind (0-5 m sec$^{-1}$). With the increase of wind velocity up to 7 m sec$^{-1}$, coefficient uniformity in relation to the increase of wind speed reduces linearly and the slope of coefficient uniformity and wind velocity curve goes almost steadily. However, in high wind speeds of more than 7 m sec$^{-1}$ the coefficient drops sharply (by 17% as measured in this study). Hart (1965) in his research found out that the effect of coefficient uniformity reduction as a Consequence of wind velocity increase for nozzle of 3.16 mm and at 9×15, 9×18, 12×18 m intervals is linear. Dechmi *et al*. (2003a) in his study have reported that wind velocity is the main environmental factor affecting sprinkler performance. For wind speeds beyond 2.1 m sec$^{-1}$ the value of CU is clearly affected by the wind speed. Urrutia (2000), under similar experimental conditions, found a decrease in the CU when the wind speeds exceeded 3.5 m sec$^{-1}$. This value almost doubles the threshold proposed by Faci and Bercero (1991).

## CONCLUSION

Three general conclusions can be inferred, from this study:

First, as a result of wind speed increase the coefficient uniformity decreased in all parameters (sprinklers layouts, operating pressures, etc.). Under windy conditions, the water distribution pattern of an isolated sprinkler is distorted and narrowed. Therefore, the CU generally shows a tendency to decrease as wind speed increases. Second, the highest coefficient uniformity was obtained in 1×5×15 m spacing while the lowest amount was gained in 21×21 m arrangements. In general, one can conclude that by increase of the sprinklers' spacing the coefficient uniformity reduces. The main reason can be relegated to greater overlapping of the sprinklers at shorter intervals. Third, the square layout enjoys the higher water dispersion uniformity and the rectangular layout has the lowest coefficient. Although this coefficient for triangular arrangement is higher than that of rectangular arrangement, due to persisting operational problems such as displacement of the pipelines in the semi-movable system. One of the decisive factors in raising the coefficient uniformity is the extent of overlapping of the sprinklers. Overlapping in square layouts are almost the same in all directions while in a rectangular arrangement they differ in latitudinal and longitudinal directions.

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