

TECHNICAL EVALUATION OF IRRIGATION UNIFORMITY IN SOLID SET SPRINKLER SYSTEMS

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ABSTRACT

Solid-set sprinkler irrigation systems are used as a modern irrigation method. Unfortunately due to lack of proper design and performance of the system in several agricultural lands, the efficiency of the Solid-set sprinkler irrigation systems is low or unacceptable. The specific objective of this study is to evaluate of water distribution uniformity of portable sprinkler irrigation systems under field conditions in Miandoab region, West Azarbaijan province at northwest of Iran. For this purpose, 10 solid set sprinkler irrigation systems were selected accidentally and were evaluated in three steps during the irrigation season in 2012 and 2013 in order to the evaluation of distribution uniformity in solid set sprinkler systems. The average of pressure difference percentage is achieved 39.8 percent in irrigation systems that extreme differences are caused in sprinklers discharge. It should be noted that average of pressure difference percentage is exceeded of designed allowed limit in many irrigation systems. So that of 10 irrigation systems evaluated, only 2 cases, the average of pressure difference percentage were below the designed allowed limit of 20 percent. Thus evaluating indicators were used such as Christiansen's Uniformity Coefficient (CU) and Distribution Uniformity (DU). The results showed that the overall average of CU and DU were obtained 59.4 and 46.3% respectively. DU variation related to CU calculated as following equation at irrigation systems.

$$DU = 0.8315CU - 3.1289 \quad R^2 = 0.934$$

One of the main reasons for low distribution uniformity is existence of wind at area and lack of proper designing.

Key words: Evaluation, Distribution Uniformity, Irrigation Systems, Sprinkler and Solid-Set

INTRODUCTION

The best usage of water resources must be considered as the main axis of agricultural progress. Evaluation is one of the components of every irrigation system to improve its management. It becomes necessary to quantify the performance of irrigation systems, both on the drawing board, as a design and management criterion, and in the field, as an operating criterion. An ideal irrigation system should apply the water uniformly. We can therefore evaluate the performance of an in-field system in term of its uniformity (Haman *et al.*, 2003).

Irrigation efficiency defines how effectively an irrigation system supplies water to a given crop or turf area. Efficiency can be computed as the ratio between water used beneficially and water applied and is expressed as a percentage (Burt *et al.*, 1997). Irrigation efficiency is difficult to quantify; therefore, distribution uniformity is often measured as an indicator of potential efficiency for sprinkler irrigated areas. Uniformity of water distribution is a measure of the variability in application depth over a given area. Sprinkler effectiveness is reduced by operation at either excessively high or low pressures. Under either condition, water is not uniformly distributed. Sprinkler irrigation system performance is often evaluated based on uniformity coefficients from water collected in an array of measuring devices (catch cans) (Elliott *et al.*, 1980; Topak *et al.*, 2005).

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Without good uniformity, it is impossible to irrigate efficiently; parts of the field will be either over-irrigated or under-irrigated. Efficient use of available water is essential because of a limited water supply and a serious drainage problem in a portion of the District. Irrigation efficiencies are directly related to the uniformity of water application (distribution uniformity) on the individual fields.

Irrigation efficiency defines how effectively an irrigation system supplies water to a given crop. Irrigation efficiency is difficult to quantify; therefore, distribution uniformity is often measured as an indicator of potential efficiency for sprinkler irrigated areas. As a result, irrigation uniformity can be a good indication of potential irrigation efficiency. Uniformity of water distribution is a measure of the variability in application depth over a given area. Two methods have been developed to quantify uniformity, distribution uniformity (DU) and the coefficient of uniformity (CU) (Melissa *et al.*, 2005).

The larger the no uniformity, the larger the differences in infiltrated water throughout the field and the more the drainage below the root zone (Hanson, 2005). The common index describing uniformity is the distribution uniformity (DU) defined as the ratio of the least amount of infiltrated water to the average amount (Hanson, 2005). Several researchers have studied the distribution uniformity of irrigation systems (Baum *et al.*, 2003; Dukes *et al.*, 2006; Smajstria *et al.*, 2005; Tariq *et al.*, 2004). Keller and Bliesner (1990), Burt *et al.*, (1997) reported that the gross irrigation water required for an irrigation event could be computed by using the potential application efficiency of the low quarter (PAE_{lq}) (Topak *et al.*, 2005).

A high uniformity is required to attain a satisfactory level of irrigation efficiency (Topak *et al.*, 2005). The sprinkler irrigation distribution patterns have been characterized by various uniformity coefficients (Al-Ghobari, 2006; Karmeli, 1978; Maroufpoor *et al.*, 2010). Christiansen's coefficient of uniformity was first used to introduce a uniformity coefficient to the sprinkler system (Christiansen, 1942; Karmeli, 1978; Maroufpoor *et al.*, 2010).

Nasab *et al.*, (2007) in their evaluation of sprinkler systems in Iran, concluded that the main problems of sprinkler irrigation systems are deficient design and implementation, low distribution uniformity, low water pressure, deficient distribution of pressure, insufficient lengths of lateral pipelines in addition to poor quality equipment and deficient management and maintenance processes (Nasab *et al.*, 2007).

Griffiths and Lecler (2001) evaluated pumping plants, overhead sprinklers, sub-surface drip (SSD), and center pivot and furrow irrigation systems. The high coefficient of uniformity recorded could be ascribed to the appropriate selection of the types of sprinklers, spacing, efficient functional pressures of the sprinkler and favourable weather conditions (Nasab *et al.*, 2007).

Melissa *et al.*, (2005) have reported from the tests on residential irrigation systems, that the average low quarter distribution uniformity (DU_{lq}) value was calculated as 0.45. Residential irrigation system uniformity can be improved by minimizing the occurrence of low pressure in the irrigation system and by ensuring proper spacing is used in design and installation. Ahaneku (2010) evaluated the performance of a new portable sprinkler system purchased by the lower Niger River basin development authority, Ilorin, Nigeria. The coefficient of uniformity (CU) was used to compute the uniformity of sprinkler water application on the field. Results of the field evaluation indicated that the average CU of the system was 86%, indicating satisfactory performance of the sprinkler system.

The main purpose of this study was to technical evaluation of irrigation uniformity in solid set sprinkler systems.

MATERIALS AND METHODS

During the irrigation season in 2012 and 2013, 10 solid set sprinkler system catch can tests were conducted in 3 steps at 10 farmer's field (DL, OH, GP, DK, LO, FS, PH, GS, LA and KO) in the area of collective irrigation in Miandoab region, West Azarbaijan province at northwest of Iran in order to the evaluation of distribution uniformity in solid set sprinkler systems. Miandoab region has a semi-arid climate, almost all set sprinkler systems used in the collective irrigation area are solid set and as most of the sprinklers have double nozzles, and this type was used in the experiments.

All tests were carried out in the early morning under low wind conditions. Pressures within zones measured at the sprinkler nozzles using pitot tube pressure gauges. Sprinkler flow rate determined by

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either measuring the volume discharged from typical sprinklers per unit time. Values of flow rate and pressure of various solid set sprinkler systems in various evaluating steps (1, 2 and 3) are given in the Table 1. Each head test was replicated three times.

Table 1: Values of parameters of flow rate and pressure in various farmer's field solid-set sprinkler irrigation systems in various evaluating steps

Farmer's Field	Step	Flow Rate Q (l/s)	Min Pressure P _n (psi)	Parameters		$(\frac{P_m - P_n}{P_n})100$ (%)
				Mean Pressure P _a (psi)	Max Pressure P _m (psi)	
DL	1	2.35	29	41	54	61.0
	2	2.47	33	43	57	55.8
	3	2.43	30	42	56	61.9
Mean DL		2.42	31	42	56	59.6
OH	1	3.00	44	48	52	16.7
	2	3.08	47	51	53	11.8
	3	3.21	49	53	56	13.2
Mean OH		3.10	47	51	54	13.9
GP	1	2.38	40	43	55	34.9
	2	2.43	41	42	54	30.9
	3	2.38	39	41	53	34.1
Mean GP		2.40	40	42	54	33.3
DK	1	2.37	30	42	55	59.5
	2	2.48	34	45	58	53.3
	3	2.45	32	42	56	57.1
Mean DK		2.43	32	43	56	56.7
LO	1	2.32	27	38	52	65.8
	2	2.41	32	40	54	55.0
	3	2.37	28	39	53	64.1
Mean LO		2.37	29	39	53	61.6
FS	1	2.51	33	44	59	59.1
	2	5.65	36	47	60	51.1
	3	5.47	35	45	57	48.9
Mean FS		2.54	34	45	59	53.0
PH	1	3.11	45	42	54	18.7
	2	3.21	48	52	55	13.5
	3	3.31	51	51	58	13.0
Mean PH		3.21	48	51	56	15.1
GS	1	2.32	35	38	50	39.5
	2	2.35	36	38	51	39.5
	3	2.27	32	35	48	45.7
Mean GS		2.31	34.3	37	50	41.5
LA	1	2.25	30	33	45	45.4
	2	2.23	29	32	43	43.7
	3	2.37	38	40	52	35.0
Mean LA		2.28	32	35	47	41.4
KO	1	1.95	25	27	31	22.2
	2	1.90	24	28	30	21.4
	3	1.82	23	27	29	22.2
Mean KO		1.89	24	27	30	22.0

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Field evaluations of uniformity of the irrigation systems described previously were conducted by adopting the methodology of Merriam and Keller (1978), Merriam *et al.*, (1980), ASAE standard S330.1 (1985a) and ASAE standard S398.1 (1985b).

Uniformity of water application is a measure of the variability in depths of water applied at different points throughout an irrigated zone. Uniformity of water application can be measured using catch cans set on or near the soil surface. Uniformity of water application with sprinkler irrigation systems is usually reported as either the distribution uniformity (DU) or Christiansen's Uniformity Coefficient (UC).

Christiansen (1942) developed the "Christiansen Coefficient of Uniformity", CU:

$$CU = 100 \left[\frac{1 - \sum \frac{X}{mn}}{1} \right] \quad (1)$$

Where, $\sum X$ is the sum of the absolute deviations from the mean (mm or ml) of all the observations, m , is the mean application depth measured (mm or ml) and n is the number of observations (catch cans).

The Distribution Uniformity (DU) emphasizes under-watered areas and compares the driest quarter of the field to the rest (Merriam and Keller, 1978):

$$DU = 100 \left[\frac{m_4}{m} \right] \quad (2)$$

Where, m is the mean depth, and m_4 is the mean depth of the lowest quarter of the observations.

Keller and Bliesner (1990) defined the system coefficient of Christiansen uniformity, CUs and the system coefficient of distribution uniformity, DUs as:

$$CUs = CU \left[\frac{1 + \left(\frac{Pn}{Pa} \right)^{0.5}}{2} \right] \quad (3)$$

$$DUs = DU \left[\frac{1 + 3 \left(\frac{Pn}{Pa} \right)^{0.5}}{4} \right] \quad (4)$$

Where; Pn , is the minimum sprinkler pressure (psi) and Pa , is the average sprinkler pressure (psi).

The values of CU, DU, CUs, and DUs were obtained from 10 solid set sprinkler systems in 3 evaluating steps. Data analysis was performed using the excel software.

RESULTS AND DISCUSSION

The average of pressure difference percentage is achieved 39.8 percent in irrigation systems that extreme differences are caused in sprinklers discharge. It should be noted that average of pressure difference percentage is exceeded of designed allowed limit in many irrigation systems. So that of 10 irrigation systems evaluated, only 2 cases, the average of pressure difference percentage were below the designed allowed limit of 20 percent.

The values of CU, DU, CUs, and DUs were obtained from various evaluating steps (1, 2 and 3) at different solid set sprinkler systems are given in the Tables 2, 3, 4 and 5 respectively.

Table 2: Values of Christiansen Uniformity (CU) in various evaluating steps in different farmer's field sprinkler irrigation systems

Step	DL	OH	GP	DK	LO	FS	PH	GS	Farmer's Field	
									LA	KO
1	44.1	75.4	70.1	43.1	43.2	45.2	62.0	70.2	50.3	45.1
2	62.3	73.1	69.8	60.1	58.9	62.3	70.1	65.3	55.3	40.8
3	70.2	69.5	65.3	71.8	68.2	50.3	67.0	60.2	54.3	38.9
Mean	58.9	72.7	68.4	58.3	56.8	52.6	66.4	65.2	53.3	41.6

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Uniformity indicators were sorted into different sprinkler spacings. The CU variability was large, ranging from 41.6 to 72.7%, with an average value of 59.4% (Table 2). The average value of CU in the 30*30m, 25*30m and 25*25m sprinkler spacing (Table 2) 49.2, 58.0 and 68.2. The results showed that when sprinkler spacing decrease, the uniformity coefficient of CU increase, although the cost increases, therefore the results showed the acceptable values of CU were obtained from low sprinkler spacing. The results obtained in this study is in agreement with that obtained elsewhere by Nasab *et al.*, (2007) that the high coefficient of uniformity recorded could be ascribed to the appropriate selection of sprinkler spacing and pressure of the sprinkler. Keller and Bliesner (1990), Allen (1993) and Tarjuelo *et al.*, (1999) have reported that CU coefficient should be more than 84%. If this is taken into consideration, the spacing that give a value of CU>84% should be less than 25m*25m (table 2).

Table 3: Values of Distribution Uniformity (DU) in various evaluating steps in different farmer's field sprinkler irrigation systems

Step	DL	OH	GP	DK	LO	FS	PH	GS	Farmer's Field	
									LA	KO
1	37.8	60.1	55.3	35.4	32.6	34.5	47.0	55.2	38.2	34.9
2	51.2	60.1	54.3	48.2	43.8	48.2	55.1	47.7	42.1	30.7
3	63.1	51.2	52.1	55.7	55.3	35.3	51.4	42.1	40.3	29.3
Mean	50.7	57.1	53.9	46.4	43.9	39.3	51.2	48.3	40.2	31.6

The DU variability was large, ranging from 31.6 to 57.1%, with an average value of 46.3% (Table 3). The average value of DU in the 30*30m, 25*30m and 25*25m sprinkler spacing (Table 3) 37.0, 47.0 and 52.6. The uniformity coefficient of DU increase, when sprinkler spacing decrease.

The low-quarter distribution uniformities (DU) can be classified by the overall system quality ratings published by the Irrigation Association (IA, 2004). The uniformities solid set sprinkler systems tested in this study (Table 3) would be considered in the "fair" (50–59) to "fail" <40 range. The 40%, 40% and 20% sprinkler systems tested in this study would be considered in the "fair" (50–59), "poor" (40–49) and "fail" <40 respectively.

Table 4: Values of Christiansen Uniformity of system (CUs) in various evaluating steps in different farmer's field sprinkler irrigation systems

Step	DL	OH	GP	DK	LO	FS	PH	GS	Farmer's Field	
									LA	KO
1	40.6	73.8	68.9	39.8	39.8	42.2	61.0	68.8	49.1	44.2
2	58.4	73.6	69.4	56.2	55.8	58.4	68.7	64.4	54.0	39.3
3	64.8	68.2	64.5	67.2	63.0	47.3	66.1	58.9	53.6	37.4
Mean	54.6	71.2	67.6	54.4	52.9	49.3	65.3	64.0	52.2	40.3

The Christiansen Uniformity of system (CUs) was ranged from 40.3 to 71.2%, with an average value of 57.2% (Table 4). The average value of CUs in the 30*30m, 25*30m and 25*25m sprinkler spacing (Table 4) 47.3, 54.0 and 67.0.

Table 5: Values of Distribution Uniformity of system (DUs) in various evaluating steps in different farmer's field sprinkler irrigation systems

Step	DL	OH	GP	DK	LO	FS	PH	GS	Farmer's Field	
									LA	KO
1	33.3	58.2	53.8	31.3	28.8	31.0	45.9	53.5	36.9	33.9
2	46.4	58.3	53.8	43.5	40.3	43.7	53.5	46.7	40.6	29.0
3	55.8	49.7	51.1	50.4	49.0	32.2	50.3	40.7	39.5	27.6
Mean	45.2	55.4	52.9	41.7	39.3	35.6	49.9	47.0	39.0	30.2

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The Distribution Uniformity of system (DUs) variability was large, ranging from 30.2 to 55.4%, with an average value of 43.6% (Table 5). The average value of DUs in the 30*30m, 25*30m and 25*25m sprinkler spacing (Table 5) 34.9, 42.1 and 51.3.

As a result it was concluded that pressure variations did negatively impact uniformity. Thus it is concluded that pressure variations was a source of nonuniformity.

Conclusion

It should be noted that average of pressure difference percentage is exceeded of designed allowed limit in many irrigation systems. So that of 10 irrigation systems evaluated, only 2 cases, the average of pressure difference percentage were below the designed allowed limit of 20 percent and pressure variations did negatively impact uniformity. It is concluded that when sprinkler spacing decrease, the uniformity coefficients of CU, DU, CUs and DUs increase.

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