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COMPARISON OF CLASSICAL SPRINKLER AND WHEEL MOVE IRRIGATION SYSTEMS IN DEHGOLAN PLAIN, NORTH-WEST IRAN†

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ABSTRACT

The performance and efficiency of classical fixed sprinkler and wheel move irrigation systems were compared in the Dehgolan Plain, north-west Iran. The field and laboratory experiments were conducted with 10 classical fixed and 10 wheel move systems. Christensen coefficient of uniformity (CU), distribution uniformity (DU), potential application efficiency of low quarter (PELQ) and application efficiency of the lower quarter (AELQ) were used for the purpose of this assessment. The results showed a low efficiency due to improper design and management of classical fixed systems. Also, the results indicated that the wheel move systems used in the Dehgolan Plain performed well. The average mean values of the above coefficients (i.e. 12.6, 19.8, 21.5 and 14.5%) were higher in wheel move systems in comparison to those of classical fixed systems. Additionally, the average mean value of wind drift and evaporation losses (WDEL) and percolation losses (DP) were 0.45 and 1.17% lower in the wheel move systems, respectively, in comparison to those of classical fixed systems. The adequacy of irrigation (AD_{irr}) of the wheel move systems was 16.3% higher than that of classical fixed systems. Generally, the results showed that wheel move systems in the Dehgolan Plain have a substantially higher efficiency than the classical fixed systems. © 2020 John Wiley & Sons, Ltd.

KEY WORDS: application efficiency; distribution uniformity; classical fixed system; potential efficiency; sprinkler irrigation; wheel move system

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RÉSUMÉ

Les performances et l'efficacité des systèmes d'irrigation classiques fixes à aspersion et à roue ont été comparées dans la plaine de Dehgolan, au nord-ouest de l'Iran. Les expériences sur le terrain et en laboratoire ont été conduites avec 10 systèmes classiques fixes et 10 mouvements mobiles. Le coefficient d'uniformité de Christensen (CU), l'uniformité de la distribution (DU), l'efficacité d'application potentielle du quartier bas (PELQ) et l'efficacité d'application du trimestre inférieur (AELQ) ont été utilisés aux fins de la présente évaluation. Les résultats ont montré une faible efficacité due à une conception et à une gestion inappropriées des systèmes classiques fixes. En outre, les résultats ont montré que les systèmes de déplacement de roue utilisés dans la plaine de Dehgolan se sont bien comportés. Les valeurs moyennes des coefficients moyens ci-dessus (c'est-à-dire 12.6, 19.8, 21.5 et 14.5%) étaient plus élevées dans les systèmes de déplacement de roue par rapport à celles des systèmes classiques fixes. De plus, la valeur moyenne des pertes moyennes par dérive et par évaporation du vent (WDEL) et des pertes par percolation (DP) était respectivement inférieure de 0,45 et de 1,17% dans les systèmes de déplacement de roue, par rapport à celles des systèmes classiques fixes. L'adéquation de l'irrigation (ADirr) des systèmes de déplacement de roue était 16.3% plus élevée que celle des systèmes classiques fixes. De manière générale, les résultats ont montré que les systèmes de déplacement de roue dans la plaine de Dehgolan ont une efficacité nettement supérieure à celle des systèmes classiques fixes. © 2020 John Wiley & Sons, Ltd.

MOTS CLÉS: efficacité des applications; uniformité de la distribution; système classique fixe; efficacité potentielle; irrigation par aspersion; système de déplacement des roues

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1. INTRODUCTION

The agricultural sector consumes 93% of the world's water (Valenzuela, 2009), and agricultural water consumption in Iran is more than 90% (Hassanli *et al.,* 2009). Iran is a country with an arid to semi-arid climate (an average annual rainfall of 240 mm) and many of its parts suffer from water scarcity issues (Mokari Ghahroodi *et al.,* 2015). According to the Falkenmark index, Iran is about to face a serious water crisis in the near future. Also, according to indices introduced by the United Nations and the International Water Management Institute (IWMI), in order to continue and maintain the status quo until 2025, Iran needs to expand its existing extractable water resources by 112%. This, however, seems to be in impossible practice considering the available resources (Sheikh Esmaelli, 2006). This clearly highlights the critical role of water resources in agricultural development (Lorenzini and De Wrachien, 2005; Lankford, 2006), especially in countries such as Iran (Abedian, 1997). The reduction of irrigation water needs is considered to be one of the most effective ways to maintain water resources, therefore, improvement of water application efficiency and management practices of irrigation systems can help achieve such objectives (Lankford, 2006; Playa'n and Mateos, 2006; Lemeister *et al.,* 2007; Hassanli *et al.,* 2009). Pressurized irrigation, among other methods, is popular, and is used to reach high efficiencies and a substantial saving of water application in the agriculture sector (McLean *et al.,* 2000; Gencoglan *et al.,* 2005; Liu and Kang, 2006; Kahlown *et al.,* 2007). Furthermore, this method has proven helpful in irrigating several plant species under most weather and soil conditions and irrigated agriculture (Gencoglan *et al.,* 2005).

The ultimate goal of system performance assessment is to achieve improved performance by effective management practices (Akbari *et al.,* 2007). Merriam and Keller (1978) defined system performance assessment based on measurements taken under field conditions and normal system operation. Hence, several indices have been recommended for comparing the actual performance of a system with its design performance. Such criteria are measurable variables that describe a system's condition and its changes in time and space (Lorenzini and De Wrachien, 2005; Akbari *et al.,* 2007), and is a reliable tool in determining the success of a system in irrigation management (Rodriguez-Diaz *et al.,* 2008). Overall, these criteria are used to determine water uniformity distribution and water application efficiency in the field (Burt *et al.,* 1997; Pereira, 1999). Most researchers are of the opinion that the water uniformity distribution parameter is a critical one in assessing irrigation systems (Perrens, 1984; Li and Rao, 2000; Dechmi *et al.,* 2003a, b).

Merriam and Keller (1978) defined different parameters such as distribution uniformity (DU), application efficiency of the low quarter (AELQ), potential application efficiency of low quarter (PELQ) and coefficient of uniformity (CU) as the major parameters in assessing pressurized irrigation systems. Although advances have been made in recent years to replace traditional surface irrigation with pressurized irrigation systems, the improvement of quality in such systems requires assessment design and operation of the implemented pressurized system and its compatibility under varying climates in the country and new management practices to increase efficiency.

Currently, 30 000 ha of cropland in Kurdistan Province, located in north-west Iran, have different types of pressurized irrigation systems, including classical fixed, wheel move, gun and the like. Also, the implementation of different pressurized irrigation systems has been supported financially (US\$2000 ha^{-1}) by the governmental agriculture organization in the province. Moreover, comparison of different pressurized irrigation systems in Kurdistan Province has not yet been made. Therefore a study was designed on different available classical fixed and wheel move systems to obtain the following objectives in the Dehgolan Plain with high different pressurized irrigation system performance, as below:

- determination of efficiency and performance potential under current conditions;
- assessment of the accuracy of design parameters and the study of executive, operational and maintenance problems of irrigation systems;
- comparison of the system's performance with different available pressurized irrigation systems used by farmers.

2. MATERIALS AND METHODS

2.1. Study area

With an area of 1909 km^2, the Dehgolan Plain extends from 25°2′ to 25°28′ N and from 47°07′ to 47°36′ E across Kurdistan Province, north-west Iran. Figures 1 (a) and (b) show the geographical location of Kurdistan Province and the Dehgolan Plain. The average annual rainfall of this region is 340 mm. The climate is semi-arid with no rain during the summer. Currently, over more than 13 000 ha of this plain pressurized irrigation systems, mostly classical fixed or wheel move systems, are used.

2.2. Field assessments

Field assessments were conducted during April 2016 to February 2017. Twenty systems including 10 classical fixed

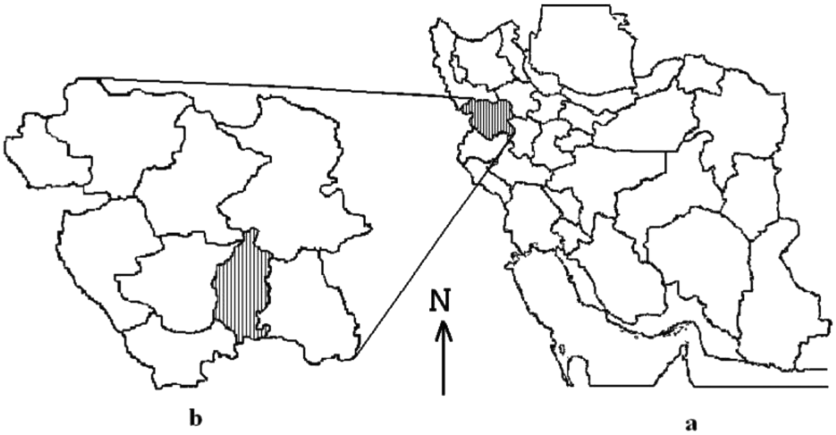

Figure 1. The position of (a) Kurdistan Province and (b) Dehgolan Plain in Kurdistan Province

and 10 wheel move systems were randomly selected for the purposes of the present study. Such systems were in operation for at least one growing season. The assessments were conducted following the methodology recommended by Merriam and Keller (1978). All the selected classical fixed systems were of both square and rectangular layout under different crop cultivation. Table I shows the specifications of the selected systems. The sprinklers of the selected wheel move irrigation systems on lateral pipes were spaced every 12 m, while different arrangements of the irrigation systems were spaced every 18 m by the operators. All the wheel move selected systems had wheels with a diameter of 2 m and the sprinkler types were of VYR35. Table II shows the specifications of the wheel move irrigation systems with different crop cultivation.

In this study, local operators were first asked to answer a questionnaire to determine their general knowledge of irrigation practices, plant water requirements and irrigation systems management with respect to irrigation duration and intervals. Then, undisturbed samples of different soil depths (including 0–25, 25–50 and 50–75 cm) were collected to determine soil special weight and field farming capacity. Additionally, in order to specify soil physical and chemical characteristics, disturbed samples were taken at different depths. Before water uniformity distribution experiments began, soil moisture was measured to determine soil moisture deficit (SMD), and hydraulic parameters of irrigation system including sprinkler pressure and discharge were measured by reading the pressure values on barometers and pitot pipes installed on sprinkler heads.

The sprinkler discharge flow was calculated by using a chronometer, a gallon in volume of 20 liters and volumetric method. Based on the topography of the region, a location to conduct the water distribution uniformity experiment was selected where the average system pressure would occur (Merriam and Keller, 1978). For example, since the classical fixed systems need to be on a flat surface or have a very low and uniform slope, the lateral pipe was installed in the middle of field and the experiment was conducted between two sprinklers 40% from the beginning of the lateral pipe.. In wheel move systems a point on the wheel move was selected where the average pressure along the pipe exists. In

Table I. Specifications of the classical fixed systems

Fields	Crop	Irrigation interval (day)	Irrigation duration (h)	Sprinkler spacing (m × m)	Sprinkler height (cm)	Sprinkler model
S1	Alfalfa	7	8	25 × 25	80	AMBO
S2	Alfalfa	5	4	26 × 26	90	AMBO & PERROT (ZM22)
S3	Wheat	7	4	25 × 25	100	AMBO
S4	Wheat	10	4	25 × 25	100	PERROT (ZK30)
S5	Alfalfa	7	6	24 × 21	90	PERROT (ZK30)
S6	Potato	7	4	23 × 25	100	AMBO & PERROT (ZK30)
S7	Alfalfa	9	6	25 × 25	130	AMBO
S8	Potato	7	4	25 × 28	100	AMBO
S9	Alfalfa	7	7	24 × 25	100	AMBO
S10	Potato	7	4	25 × 28	90	AMBO

Table II. Specifications of the wheel move systems

Fields	Crop	Irrigation interval (day)	Irrigation duration (h)	Sprinkler spacing (m × m)	Sprinkler height (cm)	Sprinkler model
W1	Alfalfa	4	4	12 × 18	120	VYR 35
W2	Alfalfa	7	7	12 × 18	120	VYR 35
W3	Alfalfa	8	8	12 × 18	120	VYR 35
W4	Alfalfa	8	6	12 × 18	120	VYR 35
W5	Alfalfa	7	8	12 × 18	120	VYR 35
W6	Potato	6	7	12 × 18	120	VYR 35
W7	Wheat	8	7	12 × 18	120	VYR 35
W8	Wheat	7	6	12 × 18	120	VYR 35
W9	Potato	7	8	12 × 18	120	VYR 35
W10	Potato	7	8	12 × 18	120	VYR 35

Table III. The average wind speed and average temperature for different systems during the assessment

Fields	Average wind speed ($\mathrm{m\ s}^{-1}$)	Average temperature (°C)	Fields	Average wind speed ($\mathrm{m\ s}^{-1}$)	Average temperature (°C)
S1	5.1	16	W1	3	18
S2	7.2	25	W2	1.5	16
S3	6.5	21	W3	3.5	17
S4	2.9	23	W4	5	18
S5	5.8	17	W5	2	20
S6	3.6	17	W6	2	20
S7	4.3	26	W7	3	24
S8	2.2	26	W8	10	24
S9	2.9	25	W9	1.5	20
S10	5.1	20	W10	2.2	22

flat lands, this point is almost 40% from the beginning of the line. After determining the appropriate location to implement experiments, the area between two sprinklers was networked by using wooden sticks (3 × 3 m), and water-collecting buckets each of 12 cm height and 9.6 cm of internal diameter were installed (Lemeister *et al.,* 2007). Then the sprinklers started operating and the buckets were measured after 1 year using a scaled pivot. Also, two or three of the buckets contained a specific volume of water when the experiment began, which were installed away from other similar buckets under the same conditions to estimate evaporation across the fields. The remaining amount of water was measured at the end of the experiment (Tarjuelo *et al.,* 1999, Playa'n *et al.,* 2005). Samples were collected from the irrigation water of the fields and taken to the laboratory to specify the chemical characteristics. Taking into consideration the lack of wind meters during the experiments, wind data were taken from the closest weather station, Ghorveh. This station is situated 47° 47′ E and 35° 10′ N and 1906 m above sea level. Wind speeds were taken 10 m above ground level and were processed into data at 2 m above ground level using the following relation:

$$V_2 = V_Z\left(\frac{2}{Z}\right)^{0.15} \tag{1}$$

where V_2 and V_z are wind speed at 2 and 10 m above ground level and Z is equal 10 m. Wind speeds and air temperature data during water distribution uniformity experiment are given in Table III.

2.3. Calculations

During the investigation the data taken by water-collecting buckets were used in deriving the parameters below:

$$CU_t = \left[1 - \frac{\sum_{i=1}^{N}\left|D_i - \overline{D}\right|}{\overline{D}\times N}\right]\times 100 \tag{2}$$

where $CU_t\mathrm{CU}_{\mathrm{t}}$ is the Christensen uniformity coefficient of the experiment block (%), $D_i\mathrm{D}_{\mathrm{i}}$ is the water depth in water-collecting buckets (mm), $\overline{D}$ is average depth of collected water (mm) and N is the number of observations.

The water distribution uniformity of lower quarter was obtained by the following relation (Topak *et al.,* 2005; Al-Ghobari, 2006; Lamaddalena *et al.,* 2007):

$$DU_t = \frac{D_q}{\overline{D}}\times 100 \tag{3}$$

where DU_t is the uniformity coefficient of lower quarter in the experiment block (%) and D_q is the average water depth in lower quarter of measured values (mm).

In order to generalize the uniformity coefficient to all types of irrigation systems, the values were adjusted using the following relation, taking into account the existing pressure difference of irrigation systems:

$$CU_S = CU_t\left[\frac{1 + \left(\frac{P_{\min}}{P_{mean}}\right)^{0.5}}{2}\right] \tag{4}$$

For this purpose, the calculated distribution uniformity values were adjusted by the following relation:

$$DU_S = DU_t\left[\frac{1 + 3\left(\frac{P_{\min}}{P_{mean}}\right)^{0.5}}{4}\right] \tag{5}$$

where $P_{\min}$ and $P_{\mathrm{mean}}\ \mathrm{P}_{\mathrm{mean}}$ are minimum and mean pressure values and $\mathrm{CU_S}$ and $\mathrm{DU_S}$ are uniformity coefficient and distribution uniformity of the system, respectively.

$$AELQ_t = \frac{D_q}{D_r} \times 100 \tag{6}$$

where $AELQ_t$ is water application efficiency in the lower quarter of experiment block (%) and D_r is average irrigation water measured from nozzle (mm).

If the average quarter water depth which stored in the soil, to be higher than the amount of water required, hence increasing water moisture to field capacity, the percolation losses will be considerable and actual efficiency will decrease. Therefore, the soil moisture deficit will replace the average stored quarter water depth in root zone in the following:

$$AELQ_t = \frac{SMD}{D_r} \times 100 \tag{7}$$

Potential efficiency of lower quarter, which is the maximum efficiency of a system, was obtained by using the following equation (Merriam and Keller, 1978) for all fields under study:

$$PELQ_t = \frac{D_q}{D_r} \times 100 \tag{8}$$

where PELQ_t is potential efficiency of lower quarter in experimental blocks.

By comparing the last three relations, it is evident that if the average of lower quarter of stored water is equal to or less than the soil moisture deficit, water application efficiency will be equal to water application potential efficiency. However, if the average one quarters of stored water is higher than the soil moisture deficit, the actual efficiency will be less than the water application efficiency. Due to pressure differences in each system, the water application potential efficiency and actual efficiency of the main system will be less than values obtained for the experiment blocks. For this purpose, the following relations (Merriam and Keller, 1978) were used in order to determine the water application potential efficiency and actual efficiency of the main irrigation system:

$$PELQ_S = (1 - ER) \times PELQ_t \tag{9}$$

$$AELQ_S = (1 - ER) \times AELQ_t \tag{10}$$

where PELQ_S is potential efficiency of lower quarter of the main system (%), AELQ_S is application efficiency of the lower quarter of main system (%). In the above relations, ER is efficiency reduction coefficient which was obtained by the following equation:

$$ER = \frac{0.2 \times (P_{\max} - P_{\min})}{P_{mean}} \tag{11}$$

where $P_{\min}$, $P_{\max}$ and P_{mean} are minimum, maximum and average pressure values (bar) of the system, respectively.

A low PELQ value indicates defective system management practices while the difference between PELQ and AELQ values shows that such problems may be related to human operators. Wind drift and evaporation losses (WDEL) were also obtained by using the following relation (Dechmi *et al.,* 2003a):

$$WDEL = \frac{D_r - \overline{D}}{D_r} \times 100 \tag{12}$$

where WDEL is wind drift and evaporation losses in per cent. Finally, deep percolation losses were determined for each field by using the relations below under complete and incomplete irrigations in per cent. The complete and incomplete irrigation conditions were also determined by the following relations:

- Complete irrigation

$$D_P = \frac{\overline{D} - SMD}{D_r} \times 100 \tag{13}$$

- Incomplete irrigation

$$D_P = \frac{V_{Z1} - (SMD \times AD_{irr} \times S_l \times S_m)}{q \times T_{irr}} \times 100 \tag{14}$$

where q is the average sprinkler discharge ($\mathrm{m}^3\ \mathrm{s}^{-1}$), T_{irr} T-$_{\mathrm{irr}}$irrigation duration (s), S_l is sprinkler spacing on lateral pipes (m), S_m $\mathrm{S}_\mathrm{m}$distance of lateral pipes from each other on the main pipe (m), $\mathrm{AD}_{\mathrm{irr}}$ is the adequacy of irrigation (%) obtained from Equation (15) and V_{Z1} $\mathrm{V}_{\mathrm{Z1}}$the total percolated water (m^3) in a region, which is larger than or equal to the soil moisture demand (SMD) and is obtained by Equation (16):

$$AD_{irr} = \frac{N_1}{N} \times 100 \tag{15}$$

where N_1 is the number of buckets in which the water was higher than or equal to SMD:

$$V_{Z1} = \sum_{i=1}^{i:D_i \geq SMD} (D_i \times A_i) \times S_l \times S_m \tag{16}$$

where A_i $\mathrm{A}_\mathrm{i}$is the area (%) covered by each collecting bucket ($\frac{1}{N} \times 100$).

3. RESULTS AND DISCUSSION

3.1. *Results of water and soil quality experiments*

In this research, all of the soil physical and chemical characteristics of fields under study were within the allowed range and no limitations were observed with respect to the allocation of different sprinkler irrigation systems. Moreover, all fields' irrigation water quality was classified as C_2S_1 based on the Wilcox diagram with no limitations.

3.2. Assessment results of classical fixed sprinkler systems

According to the study, both classical fixed and wheel move irrigation systems have been used in selected fields at the same time. Also, irrigation intervals and durations were different even for similar crops, as shown above in Table I. Table IV gives sprinkler discharge and performance pressure parameters used by classical fixed systems.

Table V shows the different evaluated parameters for 10 fields in this study, irrigated by the classical fixed system. No runoff was observed in the studied fields. As Table V shows, the Christensen uniformity coefficient and water distribution uniformity of lower quarter were lower than the values recommended by Merriam and Keller (1978), as $70\% \geq DU \geq 80\%$ and $81\% \geq CU \geq 87\%$ in all assessed systems. As seen from Table IV, due to improper design and operation of the classical fixed irrigation system in the Dehgolan Plain, the average pressure was less than required except for field S7. Moreover, because of low average pressure, sprinkler discharge was less than that recommended by design instructions, which was the main reason for low water distribution uniformity in classical fixed sprinkler systems. Maximum pressure difference in sprinklers of most classical fixed systems exceeded the allowable range, i.e. 20% of average sprinkler pressure (Table IV). Poor operation and improper management practices also caused conditions to worsen. As field observations confirmed, some farmers used several types of sprinkler with different designs and technical specifications in one single field at the same time (Table I). For example, Italian AMBO, German PERROT and also unknown sprinkler types, known by local farmers as Iraqi sprinklers, were used in a given field simultaneously. One of the operational problems was farmers using too many sprinklers together at the same time, resulting in unacceptable reduced pressure across the irrigation system (e.g. fields S2 and S8). Furthermore, using adjustable sprinklers along with full-circle sprinklers in the middle of some fields may be blamed for lowering water distribution uniformity. The results of the study show that design defects are mainly responsible for low system pressure, since maximum pressure and even pump head in some fields including fields S10, S8, S5 and S2 were lower than that required by sprinkler heads. System pressure was higher than design in some parts of field S7. As seen from Table V, actual and potential field efficiencies, except in one case, were equal, which was mainly due to deficit irrigation . In field S1 actual efficiency was less than potential due to deep percolation. The water potential application in all fields under study was within an unacceptable range due to low water distribution uniformity (Table V).

Table IV. Different discharge and pressure parameters related to evaluated classical fixed systems

Field	Sprinkler average discharge $(l\ s^{-1})$	Sprinkler pressure (bar)			Maximum sprinkler pressure differences (%)
		Minimum	Average	Maximum	
S1	2.2	3.3	3.7	4	18.9
S2	1.7	1.2	2	2.5	65
S3	2	3	3.4	3.9	26.5
S4	1.8	2.6	3.7	4.3	46
S5	1.4	2.2	2.6	3.6	53.9
S6	1.7	2.9	3.3	4	33.9
S7	2.3	3.8	4.5	5.4	35.6
S8	1.8	3.1	3.4	3.6	14.7
S9	2	3.2	3.5	3.7	14.3
S10	2	3.1	3.4	4.1	29.4

Table V. Different evaluated parameters related to classical fixed systems

Field	Different evaluated parameters						
	CU (%)	DU (%)	PELQ (%)	AELQ (%)	WDEL (%)	D_P (%)	AD_{ir} (%)
S1	76.2	64.1	55.8	45.6	13.4	39.3	100
S2	49.3	35.5	33.7	33.7	9.5	29.8	62
S3	69.7	51.9	46.7	46.7	9.3	25.5	72
S4	61.5	50.3	44.1	44.1	15.1	6.9	28
S5	59.3	37	31.6	31.6	9.9	34	68
S6	71	57.3	49.9	49.9	10.4	24	74
S7	68.4	53.5	49.6	49.6	6.3	35.8	86
S8	59.9	36.3	30.2	30.2	17.1	15.2	54
S9	67.6	57.2	51.4	51.4	10.6	33.2	84
S10	77.6	63.2	55	55	10.6	6.3	52
Average	66	50.6	44.8	43.8	11.2	25	68

Figure 2 presents the water distribution pattern after overlapping of tested sprinklers for irrigation systems used in field S7. As seen from Figure 2, due to extremely low pressure in the sprinklers, discharged water was only sprayed from a close range. As seen from Figure 3, system water distribution uniformity (DU and CU) and water application efficiency in the lower quarter (AEQL and PEQAL) were not within the recommended values of Merriam and Keller (1978).

In most of the systems studied, deep percolation as well as irrigation water sufficiency was unacceptable. Table V shows water irrigation sufficiency for the systems under study. It is observed that irrigation sufficiency is unacceptably low, such that field S1 was irrigated with only 28% of its area receiving an amount of water equal to its

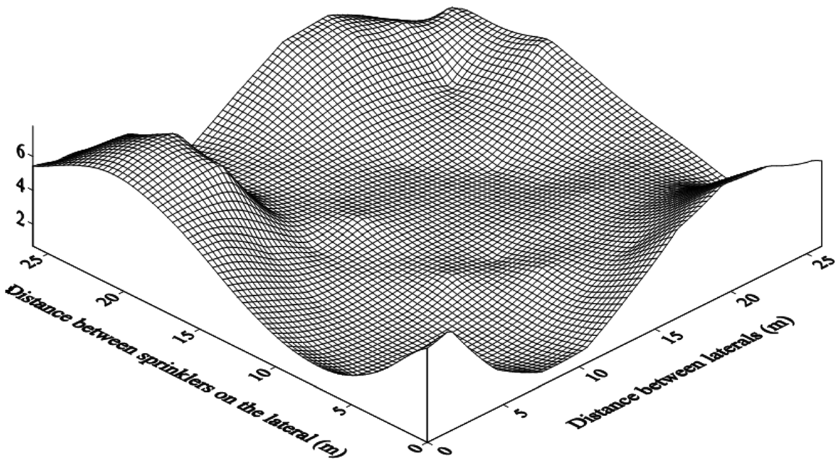

Figure 2. Water distribution pattern after sprinkler cover in field S2

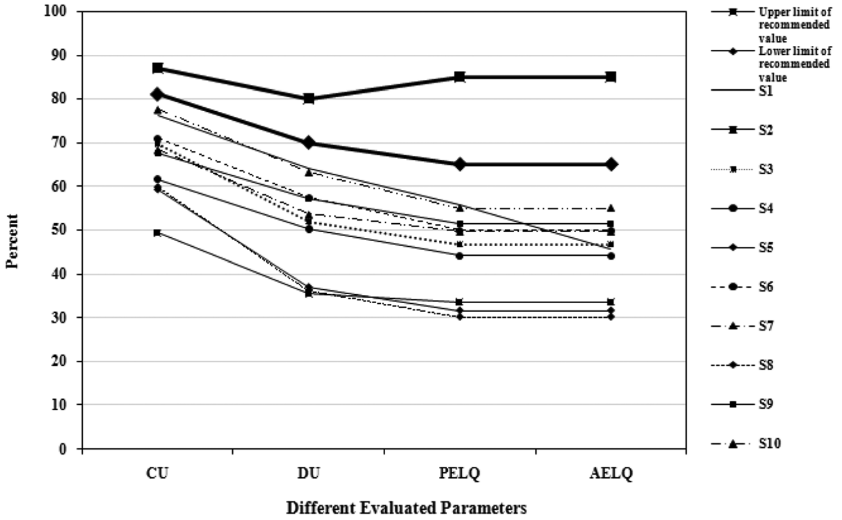

Figure 3. Different evaluated parameters obtained for classical fixed systems compared to recommended values

SMD requirements. The main reason may be low water distribution uniformity in the assessed systems, as explained above.

3.3. *Assessment of wheel move irrigation systems*

Table VI indicates the results of pressure performance and sprinkler discharge in wheel move irrigation systems. Table VII also presents the assessment parameters used in the study of fields.

No runoff was observed across the fields under this study. As seen from Table VII, Christensen uniformity coefficients of different fields W2, W4 and W8 were within the recommended range of Merriam and Keller as 81(%) ≥ CU ≥87(%), except for field W1, while water uniformity distribution of lower quarter was within the recommended range 70(%) ≥ DU ≥80(%), except for fields W3, W4 and W8. Note that the CU difference was appreciably less than its lower limit for fields W2 and W1. DU difference was also appreciably less than its lower limit for fields W4 and W8. Considering soil improving quality, both parameters are negligible. The low CU and DU in fields W4 and W8 may also be attributed to the low system pressure, wear and tear of nozzles in W4 systems as well as high wind speed (36 km h^{-1}) during assessment in field W8.

The potential efficiency was lower in fields W3, W4, W5 and W8 than that recommended by Merriam and Keller (1978). The main reason for this in fields W5 and W3 was extreme evaporation and wind losses, while reduced potential efficiency in fields W4 and W8 was caused by low distribution uniformity. In the remaining six fields, the potential efficiencies were within the recommended range 65% ≥ PELQ ≥85%.

Table VI. Different discharge and pressure parameters in evaluated wheel move systems

Field	Sprinkler average discharge $(l\ s^{-1})$	Sprinkler pressure (bar)			Maximum sprinkler pressure differences (%)
		Minimum	Average	Maximum	
W1	0.84	2.6	2.7	2.9	11.1
W2	0.49	2.3	2.384	2.6	21.4
W3	0.47	2.1	2.3	2.8	26.1
W4	0.54	2.2	2.4	2.7	20.8
W5	0.58	2.4	2.8	2.9	16.1
W6	0.56	1.9	2.1	2.2	15.6
W7	0.61	3	3.1	3.4	12.7
W8	0.46	2.2	2.4	3	33.3
W9	0.60	3.4	3.6	3.8	11.1
W10	0.60	3.4	3.6	3.8	11.1

Table VII. Different wheel move evaluated parameters

Field	Different evaluated parameters						
	CU (%)	DU (%)	PELQ (%)	AELQ (%)	WDEL (%)	D_P (%)	AD_{ir} (%)
W1	79.6	70.1	67.2	41.9	3.37	53.8	100
W2	78.1	70.7	65.1	65.1	8.18	19.7	86
W3	81.1	70	54.9	54.9	18.6	14.5	78
W4	69.4	56.4	51.8	51.8	3.3	20.8	66
W5	81.5	74.5	59.4	59.4	21.6	14.8	72
W6	84.6	78.6	71.3	51.8	8.5	38	100
W7	87.9	85.1	78.2	75.3	7.4	15.5	98
W8	64	46.8	38	38	15.8	8	43
W9	91.1	87.3	83.3	61.1	4.4	33.2	100
W10	88.2	81.8	76.5	64.7	6.3	27.5	100
Average	80.6	72.1	64.6	56.4	10.1	24.6	84.3

As seen from Table VII, in 6 out of 10 applied wheel move irrigation systems, maximum pressure difference between sprinklers across a system fell within the allowable range (20% of average sprinkler pressure). The maximum pressure difference in fields W2 and W4 exceeded allowable limits by only 1%. In fields W3 and W8, the greater pressure difference may be attributed mainly to the long length of the irrigation apparatus (372 and 336 mm, respectively), water leakage from sprinklers and technical defects in sprinkler bases (Figures 4 and 5). In five systems out of those assessed in this study, the actual efficiencies were lower than the potential.

3.4. Recommendations to increase system's irrigation efficiency

3.4.1. Actual efficiency. By reducing irrigation duration as well as deep percolation losses, actual efficiency can be increased to the potential efficiency of the irrigation system. This increase is subject to irrigation duration being a multiples of 30 min due to its applicability by mostly farmers that results in irrigation sufficiency. The modified irrigation duration is recommended for five fields with lower actual efficiencies, as presented in Table VIII.

Figure 4. Water leakage from wheel move sprinklers

Figure 5. Water leakage from a wheel move sprinkler's broken base

3.4.2. Potential efficiency. By adjusting the spacing of two consecutive arrangements, distribution uniformity and potential efficiency may change. By reducing this space, both parameters decline. From the newly recommended arrangements, only those that do not create field runoff should be used. However, it is not always possible to implement new arrangements due to practical limitations, since in reducing spacing arrangements, the recommended modified irrigation duration may not be applicable to the field under study. Thus, the irrigation period should be adjusted in the

Table VIII. Correction of irrigation duration time for different fields with lower actual efficiencies than potential efficiency

Field	Irrigation period (h)	Experimental block lower quarter efficiency (%)	Experimental block efficiency (%)	Percolation (%)	Experimental block lower quarter actual efficiency (%)	Experimental block quarter potential efficiency (%)
W1	2.5	100	94	29.1	68.5	68.7
W6	5	98.3	88	18.1	73.6	73.6
W7	6.5	96.5	81	10.2	80.3	80.3
W9	6	102.4	97.1	12.9	83.3	85.3
W10	6.5	96.1	100	13	78.3	78.3

implementation of new arrangements. By reducing spacing arrangements, the required fuel consumption and labour will increase while water and electricity consumption may be reduced. In general, the most economically feasible scenario should be selected. The present study does not give detail of the irrigation system arrangements, while it attempts to help to select the optimal scenario without considering irrigation period.

4. OPTIMAL ARRANGEMENT SELECTION

Table IX presents uniformity coefficients, distribution uniformity and potential efficiency. Table X also shows the variations of such parameters at 9, 12, 15 and 21 m spacing with respect to the conventional spacing of 18 m.

As seen from Table X, changes in spacing from 18 to 21 m reduced uniformity coefficients, distribution uniformity and potential efficiency coefficients, while reducing this spacing from 18 to 9 m in 10 fields under study increased uniformity coefficients, distribution uniformity and potential efficiency coefficients. Reducing spacing from 18 to 12 m led to an increased uniformity coefficient.

The distribution uniformity and potential efficiency were reduced only in field W10. Reducing spacing from 18 to 15 m caused reduction in uniformity coefficient in W2 while in the other cases it increased. Also, it reduced distribution uniformity and potential efficiency in W6, W7 and W10 while it increased distribution uniformity and potential efficiency in the remaining seven fields. The exception was in three fields where uniformity coefficients were more than 85% while their uniformity distributions were more than 80%. This indicates that the improvement of uniformity distribution and potential efficiency hardly occurs in higher values compared to lower ones. Also, one can conclude that any reduction in spacing arrangements in fields with high potential efficiency and uniformity coefficients will not always lead to an increase of the same coefficients.

Table XI shows the changes of potential efficiency in two different Consecutive settlement for fields W3, W4, W5 and W6. As the results showed, by reducing arrangements from 18 to 15, 12 and 9 m, the potential efficiency increased and the highest increased values were in arrangement changes from 18 to 15 m.

5. RESULTS OF COMPARISON OF CLASSICAL FIXED AND WHEEL MOVE IRRIGATION SYSTEMS

The only meaningful comparison that can be made between the two systems under study is PEQL values, since performance on the two fields can be compared as varying parameters are removed. While soil and crop conditions are not

Table IX. The evaluation parameters in different distance arrangements for wheel move systems

Field	Uniformity coefficient (%)					Distribution uniformity (%)					Potential efficiency (%)				
	9	12	15	18	21	9	12	15	18	21	9	12	15	18	21
W1	89.9	86.5	86.8	80.4	66.7	84.4	80.4	81.7	71.1	50.3	81.6	77.6	78.9	68.7	48.6
W2	87.5	82.6	85.6	80.6	67.1	83.6	74.7	75.6	74.0	43.8	76.8	68.6	69.4	68.0	40.2
W3	92.5	91.5	85.4	82	76.1	88.4	85	79.7	71.1	64.6	72	69.2	64.9	57.9	52.6
W4	84.8	85.1	80.7	70.6	56.3	78.1	79.1	78.1	57.7	37.7	73.1	74.1	73.2	54.1	35.3
W5	91.9	92.8	90.6	84.2	67.8	88	88.4	87.5	78.3	60.3	69	69.3	68.6	61.4	47.3
W6	91.2	89.4	86	86	81.7	85.8	82.1	76.1	80.5	74.6	78.5	75.1	69.6	73.6	68.2
W7	90.5	91.8	89.2	89	87.8	88.2	87.6	85.6	86.6	81.7	81.7	81.1	79.3	80.3	75.7
W8	83.4	78.4	75.9	66.1	54.2	78	67.7	63.5	48.3	31.4	65.6	57	53.5	40.7	26.4
W9	94.1	93.7	93.7	92.4	89.9	92.03	89.7	92.4	89.1	86	88	85.7	88.4	85.2	89.2
W10	92	90.1	87.9	89.8	88.7	88.04	82.9	82.2	83.5	82.8	82.5	77.6	77.1	78.3	77.6

Table X. The changes of different evaluation parameters under different settlement spaces compared to 18 m settlement spaces

Field	Uniformity coefficient changes (%)				Distribution uniformity changes (%)				Potential efficiency changes (%)			
	9	12	15	21	9	12	15	21	9	12	15	21
W1	9.6	6.1	6.4	−13.7	13.3	9.2	10.6	−20.8	12.9	8.9	10.2	−20.1
W2	6.9	2	5.1	−13.4	9.5	0.6	1.6	−30.3	8.7	0.6	1.4	−27.8
W3	10.5	9.6	3.4	−5.8	17.3	13.9	8.6	−6.5	14.1	11.3	7	−5.3
W4	14.2	14.5	10.1	−14.2	20.3	21.4	20.4	−20.1	19.1	20	19.1	−18.8
W5	7.7	8.5	6.3	−16.4	9.7	10.1	9.2	−18	7.6	7.9	7.21	−14.1
W6	5.2	3.4	0	−4.2	5.3	1.6	−4.4	−5.9	4.9	1.5	−4	−5.4
W7	1.5	2.8	0.2	−1.2	1.6	0.9	−1	−5	1.5	0.9	−0.9	−4.6
W8	17.4	12.3	9.9	−11.8	29.7	19.4	15.2	−16.9	25	16.3	12.8	−14.2
W9	1.6	1.3	1.3	−2.6	2.9	0.5	3.3	−3.2	2.7	0.5	3.1	−3
W10	2.2	0.3	−2	−1.1	4.5	−0.7	−1.3	−0.7	4.2	−0.6	−1.2	−0.7

Table XI. The changes of potential efficiency in two consecutive settlement

Reduced distance between two sprinklers (m)	Field			
	W3	W4	W5	W6
From 12 to 9	2.79	−0.96	−0.32	3.38
From 15 to 12	4.3	0.91	0.69	5.49
From 18 to 15	6.99	19.1	7.21	−3.99

discussed, variations in efficiencies are only caused by the systems themselves. According to Tables V and VII, the average PEQL is higher in wheel move systems by 19.8% than the average PEQL of classical fixed systems. This shows a better design and adaptation of wheel move systems to the operating conditions in the Dehgolan Plain. A low PEQL value in any system can be attributed to evaporation and wind losses or low water distribution uniformity or even both factors. As seen from Tables V and VII, the average evaporation and wind losses in classical fixed systems are only 1.17% higher than those of wheel move systems and do not seem to affect PEQL in both systems. It should be noted that sprinkler height from ground level and timing of assessment were similar in both systems. The sprinklers in wheel move systems were installed 1 m above ground level. The height of sprinklers above ground level, by adding the height of sprinkler fittings VYR35, was in total 1.2 m, which is almost equal to the total height of the riser and automatic valve in a classical fixed system.

By comparing the average distribution uniformity in both systems from the related tables, one can conclude that the wheel move system distributes water in a more uniform manner than the classical fixed system by 21.5%, thus causing differences in potential efficiencies of both systems. Also, it should be noted that the distribution uniformity and PEQL values in wheel move systems were in the recommended range of Merriam and Keller (1978), while none of these values in classical fixed systems were in the said range. The lack of proper water distribution uniformity and substantially reduced PEQL cause deep percolation losses while lowering AEQL at the same time. If water distribution uniformity is low, operators should irrigate any given point for a longer duration to increase irrigation sufficiency up to 75% to result in deeper percolation. As seen from Tables V and VII, the average irrigation sufficiency in fields with classical fixed systems was lower; however, average deep percolation losses were still higher than those of wheel move irrigation systems. When compared in terms of deep percolation with similar irrigation sufficiency (75%) (Table XII), the difference between average deep percolation in both systems will become more notable.

The main reasons for low water distribution uniformity in classical fixed systems were previously discussed in more detail. However, still inappropriate system pressure and high

Table XII. The percentage of deep percolation in evaluated fields

Classical fixed systems		Wheel move systems	
Field name	Deep percolation (%)	Field name	Deep percolation (%)
S1	20	W1	18.1
S2	39.3	W2	17
S3	27.2	W3	13.7
S4	26.3	W4	28.6
S5	38.2	W5	15.4
S6	24	W6	12.8
S7	26.8	W7	9.2
S8	35.1	W8	32.9
S9	30.1	W9	7.1
S10	18.4	W10	10.1
Mean	28.5	Mean	16.5

pressure differences across the system, riser and sprinkler defects as well as large spacing of sprinklers for such low water distribution uniformity can be blamed. In summary, unsuitable water distribution uniformity can be attributed to improper design and operation by farmers.

6. CONCLUSIONS

Different types of pressurized irrigation systems have been developed during the two last decades to improve irrigation and water distribution efficiency in Iran. However, operation, maintenance and management of pressurized irrigation systems require technical expertise and knowledge which make it difficult for local farmers with little knowledge to learn. Moreover, by comparing the results of performance assessments for both classical fixed and wheel move systems implemented in the Dehgolan Plain, one can conclude that if properly operated by farmers and safely reinforced against high winds, the wheel move system is strongly recommended over classical fixed systems due to its high distribution uniformity and efficiency.

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