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Research Article

TECHNICAL EVALUATION OF EFFICIENCY AND UNIFORMITY COEFFICIENTS FOR SPRINKLER IRRIGATION SYSTEMS IN HAMEDAN-IRAN

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ABSTRACT

Increasing the water efficiency is the best way in order to water saving and conservation the water resource. Every system must be evaluated after designing and implementing and its performance checked under field conditions. To evaluate the performance of irrigation systems Many of Their weaknesses is visible. The objective of this study evaluates the design and operation of implementing solid sets in the city of Bahar in Hmeadn Province of Iran. For this purpose, ten fixed irrigation systems were selected and evaluated. Sprinkler uniformity tests were conducted by using a rain gauge in order to measure the uniformity coefficients of ten fields irrigated by solid set sprinkler irrigation systems. The evaluation indicated that the mean values of Christiansen coefficient uniformity, distribution uniformity, Potential efficiency in low quarter, application efficiency in low quarter, evaporation and wind losses, deep percolation losses and effectiveness of irrigation in ten solid sets were 74.5, 64.22, 58.26, 57.90, 8.33, 21.47 and 68 percentage respectively. In eight systems, the distribution uniformity and application efficiency in low quarter were less than the amount of recommended by Merriam and Keller. The use of large numbers of sprinklers on Irrigation Laterals has been the main reason for the low uniformity coefficient and distribution Uniformity systems. Overall, the results of this study showed that the problems of design and implementation, the poor management and maintains were the reasons for the low performance of sprinkler systems located in the plain of Bahar.

Keywords: *Sprinkler Irrigation, Solid Set, Uniformity, Hamedan*

INTRODUCTION

Lack of water due to low precipitation and the recent drought are the reasons that Iran located in arid and semi arid regions. By increasing the 5 percentages of irrigation efficiency, we could save the 5billion cubic meter. The crop cannot use all of water applied by an irrigation system. Some water is lost to evaporation, deep percolation or runoff. An efficient sprinkler system is the result of good system design, proper irrigation scheduling and careful operation and timely maintenance. The water uniformity coefficient in sprinkler systems in Iran was very low and not acceptable (Bayzidi, 2004).

Good design considers such factors as pressure; nozzle size and spacing; wind, air temperature and humidity (day versus night); soil intake rate; crop rooting depth and water use rates.

The main problems in evaluation sprinkler systems were the incorrect design and implement, Week management and operations and the little knowledge about the water requirement (Shahrokhnia *et al.*, 2007). The wind speed affected on water uniformity and it was decreased with increasing the wind speed (Zapata, 2007). Wind speed and relative humidity are the important factor in evaporation and wind loss (Yacoubi *et al.*, 2012). Sprinkler selection during the system design influences uniformity. Examples of selection options include spray vs. single nozzle vs. multiple nozzle, sprinkler pressure and pressure variation, sprinkler spacing, and sprinkler location with respect to landscape features. Other factors affecting performance include wind, plant interference, and equipment damage. Installation and maintenance specifications must maintain the intent of the design to insure proper performance.

One of the inseparable exercises in irrigation projects is to be evaluated. Irrigation evaluation is defined as analysis of any irrigation method that is based upon the measurements takes under actual conditions of a land. In one evaluation of the five solid set determine the mean values of Christiansen's uniformity coefficient (CU), distribution uniformity (DU), potential efficiency of the low quarter (PELQ), application efficiency of the low quarter (AELQ) and obtained 66.88, 50.06, 44.8, 46.32 and 40.44% respectively (Salem, 2010).

The main objective of this study was to evaluate different uniformity coefficients proposed and investigate the effects of the field conditions on the end results obtained in ten solid sets.

MATERIALS AND METHODS

The present study was conducted in the Bahar plain of Hamedan province, Iran. The drainage basin of Bahar plain, also known Siminerood, is located in the northern mountain range of Alvand with an area of 2459 square kilometers Plain area (468km^2) is located between eastern longitude of 48º 17` to 48º 33` and northern latitude of 34º 49` to 35º 02`. In figure 1, the location of Bahar city in Hamedan province is shown as well as it`s evaluated fields location.

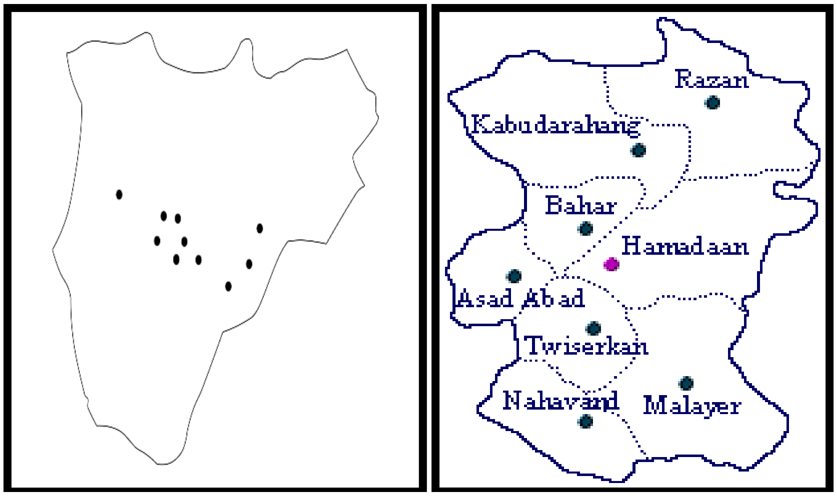

Figure 1: The location of Bahar city is shown as well as it`s evaluated fields location

The operations related to this research in Bahar plain were conducted in the spring of 2014. Most pressurized irrigation projects implemented in the region are solid-set system of sprinkler irrigation and 10 farms were selected randomly among the farms that having at least one exploitation season. It was used the opinions of Agriculture organization experts, designers and executer in this region in order to choose the solid-set systems for evaluating them During the irrigation period, selected systems were evaluated twice.

Table 1: Characteristics of the sprinkle irrigation system in the present study

System Code	Area (ha)	Irrigation systems	Water supply	Crop	Sprinkler spacing m×m	Sprinkler model
S T	4	Solid set	well	potato	12×15	Vyrsa-35
A Gh	7	Solid set	well	potato	12×12	Vyrsa-35
ShGh	6	Solid set	well	potato	12×12	Vyrsa-35
A S	2	Solid set	well	potato	12×12	Vyrsa-35
M Gh	6.3	Solid set	well	potato	12×15	Vyrsa-35
E Tsh	3.7	Solid set	well	potato	12×12	Vyrsa-35
J R	4.2	Solid set	well	potato	12×15	Vyrsa-35
A K	8	Solid set	well	potato	12×15	Vyrsa-35
M P	3	Solid set	well	potato	12×15	Vyrsa-35

Selecting the system, a questionnaire was prepared for each farm, and aforesaid system information was collected through the farmers and systems exploiters .Before irrigation, it was taken samples from different layers of soil (0-25,25-50,50-75) in each farm, and then it was determined texture, moisture content, bulk density, soil field capacity and the lack of soil moisture in the root. Double ring was used to determine the permeability of the field.

In different parts of the farm using the pressure gauges and Pitot tube, it was recorded the pressure and it was calculated the discharge of sprinklers using a stopwatch and a 20 liter gallon by the method of volume measurement. Determined the appropriate place of test in each field, the area between two sprinklers was become grid by the tape and wooden pegs while their intervals were 3*3; and for collecting of water, the cans with similar size and height of 12 cm and a diameter of 10 cm were placed in the grid points. Then after the required time (120 minutes) water in the canoes were measured by a graduated cylinder. Also, in the beginning of the experiment, one of the cans that has a certain volume of water was placed in the farm in the same condition with other clans in order to estimate the evaporation rate during the test as it was far from the sprinklers; At the end of the experiment, it was measured the volume of water remaining in that can. Therefore, the whole process of testing relating to the evaluation was repeated within a week for the second test.

To analyze the obtained data and draw diagrams and achieved the required evaluation parameters, it was used Surfer, Catch 3D and Netafim software, statistical software of Spss and Excel, as well as following relationships and formulas (Merriam and Keller, 1978).

$$CU_t = \left[- \frac{\sum_{i=1}^{N} \left| D_i - \bar{D} \right|}{\bar{D} \times N} \right] \times 100 \qquad (1)$$

Christiansen uniformity coefficient -CU_t: Christiansen uniformity coefficient, D_i:Water depth at the each collector cans (mm), N: number of observations (cans), $\bar{D}$:Average depth of water collected in cans (mm).Uniform distribution of water in the bottom quartile for all farms was calculated using the following formula:

$$DU_t = \frac{D_q}{\bar{D}} \times 100 \qquad (2)$$

Then in order to attribute the calculated uniformity coefficients to the whole system, it is adjusted these amounts according to pressure difference in each system using the following formula:

$$ECU_s = CU_t \times \left[\frac{1 + \left(\frac{P_{min}}{P_{mean}} \right)^{0.5}}{2} \right] \qquad (3)$$

For this purpose, it was adjusted the calculated uniformity distribution according to the present pressure difference in each of systems through following formula:

$$DU_s = DU_t \times \left[\frac{1 + 3\left(\frac{P_{min}}{P_{mean}} \right)^{0.5}}{4} \right] \qquad (4)$$

In this equation,P_{min} و P_{mean}, CU_s, $DU_s$is minimum pressure, average of system pressure, uniformity coefficient, and uniformity distribution of system, respectively. It was used following equation for calculating the efficiency of water use in the bottom quartile for experiment block:

$$AELQ_t = \frac{D_q}{D_r} \times 100 \qquad (5)$$

$AELQ_t$: Efficiency use of water in the bottom quartile of land in Block Test

D_r: Average depth of water, measured from the nozzle (mm).If a quarterly average of the depth of storable water in soil is more than the amount of the water needed to bring the soil moisture from the present caseof growing capacity, the deep percolation losses will be relatively high and actual efficiency will be reduced and it will be placed SMD (soil moisture deficit) in the numerator instead of quarter average of depth of stored water in root.

$$EAELQ_t = \frac{SMD}{D_r} \times 100 \qquad (6)$$

Potential application of efficiency in the bottom quartile (PELQ), that is maximum probable efficiency for available system, also was calculated through (Merriam and Keller, 1978) formula for all fields:

$$\mathrm{EPELQ_t} = \frac{\mathrm{D_q}}{\mathrm{D_r}} \times 100 \qquad (7)$$

$\mathrm{PELQ_t}$: Potential application of efficiency in bottom quartile in tested blocks.

It is clear by comparing the last three equations that if the average of a quarter of the water stored in the soil is equal to or less than the moisture deficit of soil, then the application efficiency will be equal to the efficiency of application potential.

However, if a quarter average of stored water depth is more than moisture deficit, then actual efficiency will be less than the efficiency of application potential. Due to the pressure difference in each of the systems, efficiency of application potential and actual efficiency of application, relating to whole of the system is less than their amounts for test block. For this purpose, the following equations are used to calculate the efficiency of application potential and actual efficiency of application relating to the whole system:

$$\mathrm{PELQ_s} = (1 - \mathrm{ER}) \times \mathrm{PELQ_t} \qquad (8)$$

$$\mathrm{AELQ_s} = (1 - \mathrm{ER}) \times \mathrm{AELQ_t} \qquad (9)$$

PELQs: Efficiency of application potential of bottom quartile of whole system

$\mathrm{AELQ_s}$: Application efficiency of the bottom of the quartile of system. In two last formulas, ER is the reduction coefficient of efficiency that is obtained through following relation:

$$ER = \frac{0.2 \times (P_{max} - P_{min})}{P_{mean}} \qquad (10)$$

$\mathrm{P_{min}}$, $\mathrm{P_{max}}$, $\mathrm{P_{mean}}$ Are minimum pressures, maximum pressure, and mean pressure, respectively.

Losses caused by evaporation and wind:

$$\mathrm{WDEL} = \left(1 - \frac{\overline{\mathrm{D}}}{\mathrm{D_r}}\right) \times 100 \qquad (11)$$

Spraying efficiency:

$$\mathrm{IE} = \frac{\overline{\mathrm{D}}}{\mathrm{D_r}} \times 100 \qquad (12)$$

Infiltration losses:

$$\mathrm{DP} = \frac{(\overline{\mathrm{D_0}} - \mathrm{SMD}) \times \frac{\mathrm{N_1}}{\mathrm{N}}}{\mathrm{D_r}} \times 100 \qquad (13)$$

$\mathrm{N_1}$, $\overline{\mathrm{D_0}}$ are number and average depth of collected water into the cans that existing water into them is more than moisture deficit of soil .N is total number of cans.

Compound efficiency:

$$\mathrm{E}F_{\mathrm{c}} = \frac{(100 - \mathrm{DP})(100 - \mathrm{WDEL})}{100} \qquad (14)$$

Application efficiency (depth of infiltrated water to compensate for SMD divided by the gross depth of water measured in nozzle) is obtained through following relation:

$$\mathrm{AE} = (100 - \mathrm{WDEL} - \mathrm{DP}) \qquad (15)$$

RESULTS AND DISCUSSION

After performing experiments and calculating the index of system evaluation, these indices were calculated and evaluated for each of systems in two steps separately. Average pressure and average discharge in evaluation systems in this study were obtained 36/85 (psi), 0.5 liter, respectively. In addition, in most systems, especially ST, MGh, JR, MP, Etsh systems, the average pressure was inappropriate and it was less than design pressure and pressure difference in different points of system was more than it; Except AS, AGh systems in those average pressures were appropriate and pressure difference was desired in various points. In general, due to defective design, improper implementation and weak exploitation, the pressure in the system was inappropriate. Uniformity coefficient, uniformity of distribution, system uniformity coefficient, system distribution uniformity, Actual and potential efficiency values of water in the bottom quarter, which were obtained through relations and several experiments, are presented in table 2.

Table 2: Results of evaluation parameters in the solid set sprinkler systems

System code	CU (%)	DU (%)	DUs (%)	CUs (%)	PELQ (%)	AELQ (%)	PELQs (%)	AELQs (%)
S T	82.99	71.96	68.32	71.82	61.92	61.92	54.77	54.77
A Gh	84.29	75.25	73.65	83.09	71.84	68.84	70.77	67.81
ShGh	70.94	64.38	62.32	69.43	55.83	55.22	54.31	53.71
A S	89.58	84.50	83.66	88.98	77.72	77.72	76.49	76.49
M Gh	80.77	74.44	71.40	78.58	68.55	68.55	65.43	65.43
E Tsh	80.89	72.02	70.03	79.40	63.89	63.89	60.39	60.39
J R	72.95	57.92	53.96	69.64	52.34	52.34	49.55	49.55
A K	76.13	61.54	60.34	75.14	57.11	57.11	55.75	55.75
M P	66.01	48.19	45.04	63.06	46.31	46.31	43.49	43.49
E H	67.28	55.19	53.51	65.89	52.89	52.89	51.64	51.64
average	77.18	66.54	64.22	74.50	60.84	60.48	58.26	57.90

Uniformity of water distribution is calculated through the extent or depth of the sample in the lowest quarter. Calculating of Christiansen uniformity coefficient using the same data, led to achieve higher value because this value is very close to the average depth in the bottom half. In order to achieve higher value, it is necessary to reduce the distance between the sprinklers. Generally, whatever the distances between sprinklers are closer together, the system cost will be more expensive (Merriam and Keller, 1987). Table 2 shows the Christiansen uniformity coefficient and distribution uniformity (after correcting them according to pressure difference in system).As it can be seen, Christiansen uniformity coefficient and distribution uniformity for all evaluated systems are less than value suggested by Merriam and Keller (Christiansen uniformity coefficient) is 81 to 87 percentage and distribution uniformity is 67 to 80% except AGh and AS systems. That Christiansen uniformity coefficient is 83.09, 88.98% and distribution uniformity in these systems is 73.65 to 83.66.Main reason of low value of these parameters is low pressure and discharges of sprinklers that can be seen in table 6. In addition, exploitation and poor management in most of these systems are additional reasons. Other problems of exploitation and management is using high number of sprinklers (simultaneously) by some farmers, leading to drop pressure in systems unacceptably. In addition to whole-round sprinklers, there are regulated sprinklers across the some fields; so that this reason also can be an additional reason of low distribution uniformity. Actual efficiency, potential efficiency of bottom quarter is lower than suggested values by Merriam, Keller (65 to 85 percent) in all evaluated systems except MGh, AS, AGh. The efficiency average of actual applications and potential efficiency of the bottom quarter in all evaluated systems of this study were 57/90, 58/26, respectively, that are very lower than the suggested values by Merriam, Keller (65 to 85). All systems except of two ShGh, AGh, were equal in the bottom quarter because of lower irrigation, potential efficiency, and water application and just in two systems, extra irrigation has been performed; and there have been considerable depth alleviation. Due to the pressure difference in the system, the potential and actual efficiency in the bottom quarter of the entire system have less value than test piece. In cases where the actual efficiency of application is less than the potential application efficiency, it can be said that extra irrigation is performed and farm has received more water than its need. Since there was a considerable elevation, so field managers can prevent the infiltration losses through decreasing the irrigation period and he can increase the actual application efficiency as much as potential efficiency of the bottom quarter (Khodamoradi and Moradi, 2009).Approximately equally of potential and actual efficiency represents that irrigation is performed less than required amount and this is one of good management indicators because by selecting appropriate time and period of irrigation, it is possible to increase the actual application efficiency as much as potential efficiency. Low irrigation led to increase of actual efficiency (Khodamoradi and Moradi, 2009).

In all tested systems, evaporation and wind losses are on the authorized and recommended range that its average is 8/33 and it is between the boundaries of 13/89 to 4/12 percent. Mean infiltration in proposed systems is 21/47 percent and its minimum and maximum were 8/41 and 40 percent, respectively. Moreover, although there is much infiltration in most systems, irrigation efficiency has been relatively low and unacceptable. It has been observed in some fields, irrigation efficiency is unacceptably low so that in MGH system just only 42/5 percent of irrigated area has received water as much as or more than moisture deficits of soil. The main reason for this occurrence is low distribution uniformity in evaluating systems.

Table 3: Parameters related to the efficiency and losses in the systems evaluated

System code	DP(%)	Ec(%)	Adii(%)	AE(%)	IE(%)	WDEL(%)
S T	9.12	78.30	50.00	76.99	86.11	13.89
A Gh	27.25	69.60	93.75	68.35	95.61	4.39
ShGh	27.99	62.50	78.13	58.72	86.71	13.29
A S	8.41	84.31	68.75	83.63	92.04	7.96
M Gh	9.53	83.24	42.50	82.61	92.14	7.86
E Tsh	19.17	71.71	84.38	69.46	88.63	11.37
J R	18.22	74.02	60.00	72.61	90.83	9.17
A K	26.46	68.23	72.50	66.46	92.92	7.08
M P	40.00	57.40	75.00	55.83	95.83	4.17
E H	28.56	68.56	55.00	67.33	95.88	4.12
average	21.47	71.79	68.00	70.20	91.67	8.33

Figure 2 shows the irrigation efficiency in MP, MGh fields. As it is observed there are some points on the each curve that indicates the collected water depth in each of overlapping grid cans in distribution uniformity test ,which are drawn after simulation for required time of irrigation that farmer needs. Each of dishes indicates the same area of irrigated farm. In fact, proposed curves show the frequency histogram of irrigation according to percentage.

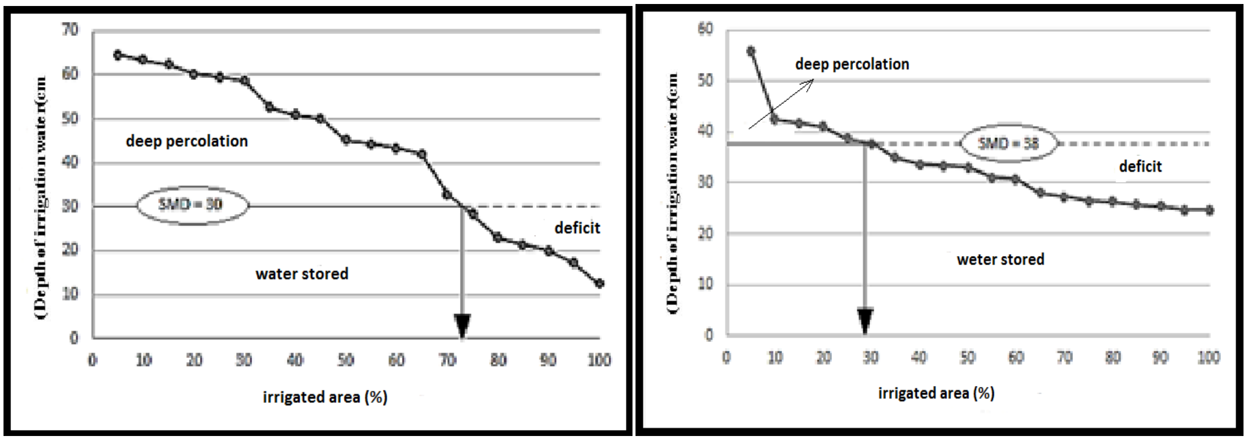

Figure 2: Adequacy of irrigation curve MP, MGh System

Figure 3 shows a distribution model after overlapping of testing sprinkler as a sample for MGh, MP systems. Studies have shown there has been designing problems relating to a low-pressure system, because maximum pressure and pump pressure in some fields is less than the required pressure for the outlet of sprinklers.

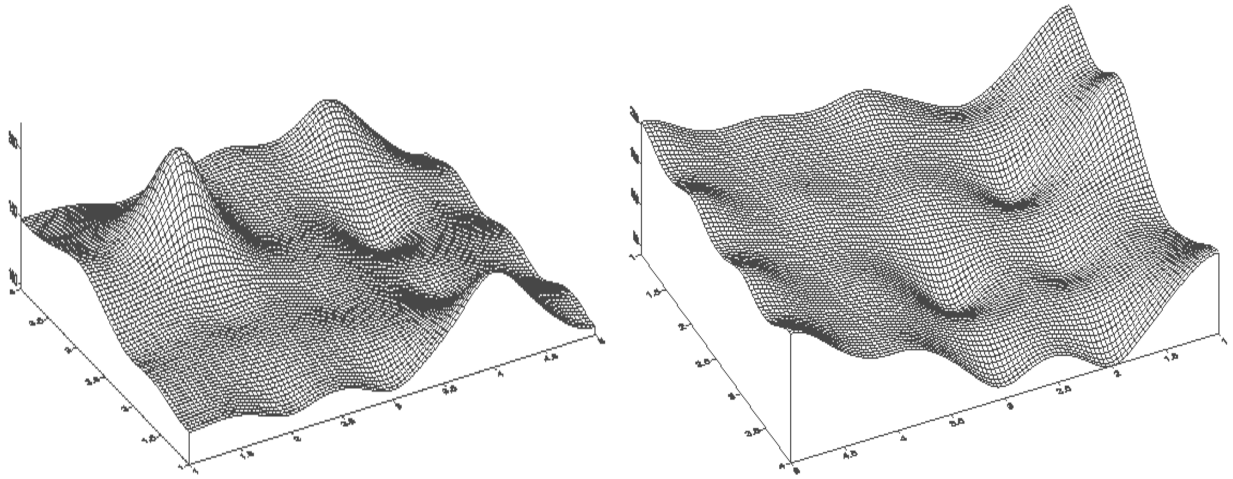

Figure 3: Shows distribution model after overlapping of tested sprinkler as a sample for MGh, MP systems

Conclusion

The results of this study showed that solid-set systems implemented in Bahar plain did not operate appropriately. Generally, designing and implementation problems as well as poor management and operation of these systems are reason of low performance of solid-set system of irrigation in Bahar plain.

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