Field Performance Evaluation of Micro Irrigation Systems in Iran

Mohammad ZAMANIYAN[1], Rouhollah FATAHI[1] and Saeed BOROOMAND-NASAB[2]

[1]Department of Water Engineering, Faculty of Agriculture, Shahrekord University, Shahrekord, Chaharmahal and Bakhtiari, Iran; [2]Department of Irrigation and Drainage, Faculty of Water Science Engineering, Shahid Chamran University, Ahwaz, Khuzestan, Iran

Abstract

Zamaniyan M., Fatahi R., Boroomand-Nasab S. (2014): **Field performance evaluation of micro irrigation systems in Iran**. Soil & Water Res., **9**: 135–142.

The efforts to introduce the micro irrigation system in Iran go back as far as the year 1990. The area under micro irrigation system in Iran covers about 400 000 ha and it is estimated to double (800 000 ha) during the next five years. The field performance of micro irrigation systems was studied in ten Iranian sites. Physical, chemical, and biological analyses of water samples derived from each site included pH, electrical conductivity (EC), total suspended solids (TSS), total dissolved solids (TDS), Fe, Mn, Mg, Ca, and bacterial number (BN). In this study relative emitter discharge (R), percentage of completely clogged emitters (P_{clog}), emission uniformity (EU), absolute uniformity emission (EU_a), statistical uniformity (Us), coefficient of variation due to emitter performance in the field (V_{pf}), and sector emission uniformity (EUs) were evaluated. Results showed that performance of micro irrigation systems in Iran is low and poor. Average EU, Us, and V_{pf} values in different sites were 52.8, 61.3, and 38.2%, respectively. Most frequent problems detected in irrigation units were: inadequate working pressure, emitters clogging, and lacking farmers' training.

Keywords: emitter clogging; emission uniformity; statistical uniformity

Micro irrigation system (MIS) is gaining importance in the world, especially in areas with limited and expensive water supplies, since it allows limited resources to be more fully utilized. The extent of micro irrigated areas grew gradually from 1.1 million ha in 1986 to about 3.0 million ha in 2000. Today, the micro irrigation has been practiced in more than 70 countries covering an area of over 6 million ha and the area extended twice just during the last six years (Sne 2006).

Efficient use of water resources and improving water productivity is one of the important issues and priorities of the Islamic Republic of Iran, especially in the last two decades. This is highlighted in the national policies and in various five-year national development plans of the country. In Iran, efforts have been made to introduce MIS at farmer's level since 1990. The yield has increased by up to 50% while saving water at a significant level. In Iran, the area under MIS is about 400 000 ha and based on estimates it should double in the next 5 years. Development of water saving irrigation systems and technologies, especially pressurized irrigation systems in the irrigated area, has been one of the important goals of the policy makers and planners in the agriculture sector. However, despite considerable attention devoted to the sustainable development of pressurized irrigation systems in Iran, the irrigated lands equipped with these systems cover still only 10.2% (0.89 million ha) of the total irrigated areas (8.7 million ha) of the country. In Iran, trees are the main plants irrigated by MIS (Heydari & Dehghanisanij 2011). The development plan of the pressurized irrigation systems in the country is provided in Table 1.

The values given in the Table 1 indicate an evident gap – a lot of work is ahead of us to achieve the required pressurized irrigation systems network in the

Table 1. Trend of development of pressurized irrigation systems in Iran (Heydari and Dehghanisanij 2011)

National development plans	Planned	Achieved	Percent of achievement (%)
	(thousands of ha)		
1st plan and before (1990–1994)	277	67	24.2
2nd plan (1995–1999)	807	204	25.3
3rd plan (2000–2004)	609	216	35.5
4th plan (2005–2009)	500	381	76.2
5th plan (2010–2014)	1000	74.8*	7.5

*this plan has not been officially started yet and the data are just for the start of the year 2010

country. Improvement of on-farm irrigation efficiency is important not only to enhance the overall irrigation efficiency of the irrigation district but also to increase the crop water productivity. Beside better use of other farm inputs like seed, fertilizers and energy, to increase crop yields under conditions of shortage of water for irrigation the use of sprinkler and micro irrigation methods has steadily been increasing globally. At the same time, these pressurized irrigation techniques should not be considered as a panacea for improvement of on-farm water management. Experience has shown that if these systems are not designed, operated, and maintained properly, they may not give the expected benefits and even in some situations may adversely affect the crop growth. It is therefore essential to carry out periodic diagnostic analyses and performance evaluations of the pressurized irrigation systems to ensure that they are operating optimally (Ghinass 2008).

Distribution uniformity of the irrigation system is accepted as one of the key criteria for evaluating the irrigation system performance. The uniformity of the infiltrated water through furrow and border in surface irrigation systems, the uniformity of water collected in catch cans in sprinkle irrigation systems, and the uniformity of emitter discharges in MIS are overall measurements which are taken into consideration through performance evaluation (Wu & Barragan 2000).

The objective of the present study was to evaluate the performance of MIS after several years of its use in strenuous conditions in Iran.

MATERIAL AND METHODS

Experimental sites. Iran has 165 million ha of arable land out of which only 8 million ha are irrigated, 6 million ha are rain-fed, and 4.5 million ha remain in the form of fallow land. Climate of Iran exhibits one the greatest extremes due to its geographic location and variation in topography. The summer is extremely hot in its central deserts while temperatures fall far below zero in the West Mountains. Annual rainfall ranges from less than 50 mm in the deserts to more than 1600 mm on the Caspian Plain. The average annual rainfall is 252 mm and approximately 90% of the country is arid or semiarid. Taken as a whole, about two-thirds of the country annually receives less than 250 mm of rainfall. Most of the rainfall is registered during the winter season, particularly in the northern parts of the country. In the central and southern parts of Iran, the annual rainfall ranges 0–200 mm (Aali *et al.* 2009).

A field study involving MIS was conducted at ten Iranian sites (Table 2) of various locations during summer 2012 (Figure 1). Climate classifications given in Table 2 are according to UNESCO (Ghafari *et al.* 2004).

The evaluations have been carried out according to Merriam and Keller's (1978) recommendations,

Figure 1. Distribution of the experimental sites over the country

Table 2. Characteristics of different locations

Location	Province	Coordinate	Elevation (m a.s.l.)	Climate	Crops	Annual rainfall (mm)
Shahrekord	Chaharmahal and Bakhtiari	32°26'37''N 50°51'34''E	2112	semi arid[1]-cold[2]-warm[3]	peach and almond	319
Borazjan	Bushehr	29°15'28''N 51°11'56''E	52	arid-moderate-very warm	lime	293
Izeh	Khuzestan	31°46'38''N 49°48'4''E	787	semi arid-cool-very warm	olive	639
Damghan	Semnan	36°4'49''N 54°20'15''E	1091	arid-cool-warm	pistachio	115
Sari	Mazandaran	36°36'18''N 53°5'15''E	13	semi humid-cool-warm	orange	1019
Ghom	Ghom	34°44'38''N 50°58'47''E	862	arid-cool-very warm	pistachio	121
Nahavand	Hamadan	34°8'29''N 48°25'29''E	1704	semi arid-cool-warm	apple and apricot	526
Talesh	Gilan	37°51'51''N 48°56'52''E	zero	permanent humid-cool-warm	kiwi	1048
Semirom	Isfahan	31°32'48''N 51°33'34''E	2381	semi arid-cold-warm	apple	393
Shahinshahr	Isfahan	32°49'25''N 51°35'30''E	1584	arid-cool-warm	pomegranate	168

[1]moisture regime; [2]winter regime; [3]summer regime

followed also by other authors (Keller & Bliesner 1990; Ortega *et al.* 2002; Yavuz *et al.* 2010; Noori & Thamiri 2012).

Water quality. Water samples were taken during the field test to determine the most important factors affecting emitter clogging (Nakayama & Bucks 1991; Capra & Scicolone 1998): electrical conductivity (EC), pH, total suspended solids (TSS), total dissolved solids (TDS), total iron (Fe), calcium (Ca), magnesium (Mg), manganese (Mn), bicarbonates (Bc), and bacterial number (BN). Water analyses were carried out in the laboratory; chemical and microbial changes in some factors were stopped by appropriate sample treatment (APHA 2005).

Emitters. The hydraulic characteristics of the emitters for all locations were taken over from the irrigation system manufacturer's manual and listed in Table 3. According to ASAE Standards (2003) defining coefficient of variation (CV_m) for emitters manufacturing, emitter types in Shahrekord, Damghan, Sari, Nahavand, and Semiromsites were classified as excellent ($CV_m < 0.05$), whereas emitter types in Borazjan, Izeh, Ghom, Talesh, and Shahinshahr were classified as poor and unacceptable ($CV_m > 0.11$).

Evaluation parameters. According to the measured data, the parameters obtained to characterize uniformity were as follows (Liu & Huang 2009):

(1) Relative emitter discharge (R) was calculated as:

$$R = \frac{\bar{q}}{q_{ini}} \quad (1)$$

where:

$\bar{q}$, q_{ini} – mean emitters discharge for each measurement (l/h) and emitters nominal discharge (l/h), respectively

(2) Percentage of completely clogged emitters (P_{clog}) was calculated as:

$$P_{clog} = 100\left(\frac{N_{clog}}{N}\right) \quad (2)$$

where:

N_{clog}, N – number of completely clogged emitters and the total number of emitters in experimental manifold, respectively

(3) Emission uniformity (EU) is one of the most frequently used design criteria for MIS. It is one of the indices for evaluation of micro irrigation per-

Table 3. Hydraulic characteristics of emitters

Locations	Emitter type	Discharge (l/h)	Manufacturing coefficient of variation	Emitter discharge exponent
Shahrekord	micro flapper, on-line, pressure compensation	4	< 0.05	0.05
Borazjan	dripper, in-line, labyrinth	4	> 0.15	0.7
Izeh	dripper, on-line, labyrinth	8	< 0.11	0.7
Damghan	micro flapper, on-line, pressure compensation	8	< 0.05	0.05
Sari	toro, on-line, pressure compensation	8	< 0.05	0.04
Ghom	dripper, on-line, labyrinth	8	< 0.11	0.7
Nahavand	netafim, on-line, pressure compensation	4	< 0.025	0.01
Talesh	microjet, on-line	142	> 0.15	0.5
Semirom	micro flapper, on-line, pressure compensation	8	< 0.05	0.05
Shahinshahr	bubbler, on-line	30	> 0.15	0.7

formance recommended by the ASAE Standards (ASAE 1982).

$$\mathrm{EU} = 100\frac{\bar{q}_{1/4\,\min}}{\bar{q}} \qquad (3)$$

where:

$\bar{q}_{1/4\min}$ – mean discharge of lower quartile (l/h)

$\bar{q}$ – mean discharge of emitters in irrigation unit (l/h)

The evaluated system is classified according to the EU values, following MERRIAM and KELLER (1978) and CAPRA and SCICOLONE (1998) (Table 4).

(4) Absolute uniformity emission ($\mathrm{EU_a}$) that is defined by KELLER and KARMELI (1974), and it considers not only the possible effects derived from the lack of water in certain points of the plant zones, but also the excess produced as a consequence of the application heterogeneity of the system. Its expression is given in Eq. (4).

$$\mathrm{EU_a} = 100\left(\frac{1}{2}\right)\left(\frac{\bar{q}_{1/4\,\min}}{\bar{q}} + \frac{\bar{q}}{\bar{q}_{1/8\,\max}}\right) \qquad (4)$$

where:

$\bar{q}_{1/8\min}$ – average flow perceived by the 1/8 of plants which perceive the highest flow in the test subunit (l/h)

Table 4. System classifications according to emission uniformity (EU) values

EU (%)	Classification	
	MERRIAM and KELLER (1978)	CAPRA and SCICOLONE (1998)
< 66	poor	low
66–70	poor	mean
70–80	acceptable	
80–84	good	
84–90	good	high
> 90	excellent	

(5) Statistical uniformity (Us) between the emitters is determined by Eq. (5) (BRALTS & KESNER 1983).

$$\mathrm{Us} = 100(1 - V_q) = 100\left(1 - \frac{S_q}{\bar{q}}\right) \qquad (5)$$

where:

Us – statistical uniformity (%)

V_q – overall change in emitters discharge

S_q – standard deviation of emitters discharge (l/h)

Statistical uniformity is evaluated according to ASAE (2003) and CAPRA and SCICOLONE (1998), based on the classification criterion presented in Table 5.

(6) Coefficient of variation due to emitter performance in the field (V_{pf}) according to BRALTS (1986) is:

$$V_{pf} = 100\left(V_q^2 - x^2V_h^2\right)^{0.5} = 100\left(V_q^2 - x^2\left(\frac{S_h}{\bar{h}}\right)^2\right)^{0.5} \qquad (6)$$

where:

V_{pf} – coefficient of variation of emitters discharge at the constant pressure

Table 5. System classifications according to statistical uniformity (Us) values

Us (%)	Classification	
	ASAE (2003)	CAPRA and SCICOLONE (1998)
< 60	unacceptable	low
60–70	poor	
70–71	acceptable	
71–80	acceptable	mean
80–89	good	
89–90	good	high
> 90	excellent	

x – emitter flow-rate exponent
V_h – coefficient of variation of the pressure head
S_h – standard deviation of pressure measured in irrigation unit (N/m^2)
$\bar{h}$ – mean pressure in irrigation unit (N/m^2)

Coefficient of variation due to emitter performance in irrigation unit is evaluated according to ASAE (2003) and Capra and Scicolone (1998), following the classification criterion shown in Table 6.

(7) Sector emission uniformity (EUs) that is determined starting from the tested subunit EU, and then correcting it by a multiplicative (f) that considers pressure distribution among the subunits that constitute the irrigation sector (Eq. (7)). Correction factor (f) calculations based on pressure distribution are stated in Eq. (8).

$$EUs = f \times EU \quad (7)$$

$$f = \left(\frac{\bar{P}_{1/4\,min}}{\bar{P}}\right)^x \quad (8)$$

where:
$\bar{P}_{1/4min}$, $\bar{P}$ – mean of low quarter and average pressure values (N/m^2), measured at the beginning of the lateral pipe and in each subunit of the operational irrigation unit, respectively

RESULTS AND DISCUSSION

Water quality. The physical, chemical, and biological properties of water from the experimental sites are listed in Table 7, and were compared with the water quality criteria for emitter clogging proposed by Bucks *et al.* (1979) and Capra and Scicolone (1998). According to Bucks *et al.* (1979), based on their properties (pH, TDS, TSS, Fe, Mn) the tested irrigation waters can be classified, in general, as minor hazardous to severe hazardous in some cases. According to Capra and Scicolone (1998), the hazard rating is, in general, from minor to moderate for EC except Ghom where it was severe, minor for TSS, from minor to moderate for Ca except Ghom where it was severe, from minor to severe for Mg, minor for Fe and Mn. The bicarbonate values for Izeh, Damghan, Sari, Ghom, Nahavand, and Talesh waters were high.

Bicarbonate concentrations of more than 305 mg/l caused serious problems due to precipitates in the irrigation system (Ayers & Westcot 1985). In Talesh, large formations of biological biofilm were observed, which occurred also in the micro jet orifice (Figure 2).

Table 6. System classifications according to variation coefficient of emitter performance (V_{pf}) values

V_{pf} (%)	Classification	
	ASAE (2003)	Capra and Scicolone (1998)
> 29	unacceptable	low
20–29	unacceptable	mean
15–20	poor	
11–15	acceptable	
10–11	acceptable	high
5–10	good	
< 5	excellent	

Evaluation parameters. The partially and completely clogged emitters were analyzed using the relative emitter discharge (R). According Capra and Scicolone (1998), R is divided into three classes: high (≥ 0.79), moderate (0.79–0.61), and low (< 0.61). As shown in Figure 3, R value for Shahrekord site was very high because of the damage of the elastic membrane by nail and installation of emitter on lateral side in an inverted position for exit excess discharge. The result implies that pressure compensation types of emitters show a better anti-clogging potential than the labyrinth types of emitters, and this result

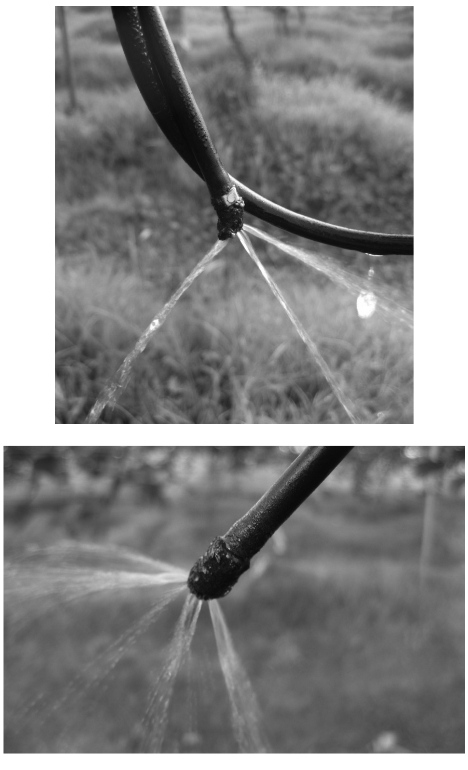

Figure 2. Formation of biological biofilm in micro jets in Talesh

Table 7. Results of water samples analyses and classification related to potential hazard of emitter clogging

Location	pH		EC		TDS		TSS			Ca		Mg		Fe			Mn			BN		Bc
		HR1	dS/m	HR2	mg/l	HR1	mg/l	HR1	HR2	mg/l	HR2	mg/l	HR2	mg/l	HR1	HR2	mg/l	HR1	HR2	cfu/cm^3	HR1	mg/l
Shahrekord	8.2	S	0.3	m	165	m	5	m	m	42.5	m	13.3	m	0.027	m	m	0.001	m	m	640	m	122
Borazjan	7.9	M	1.9	M	972	M	57	M	m	44	m	22	m	0.199	m	m	0.095	m	m	80	m	61
Izeh	8.1	S	0.5	m	196	m	18	m	m	176	m	131.8	S	0.029	m	m	0.017	m	m	1216	m	1342
Damghan	8.3	S	2.5	M	1194	M	10	m	m	384	M	24.4	m	0.034	m	m	0.021	m	m	150	m	1464
Sari	7.6	M	1.9	M	1068	M	57	M	m	344	M	97.6	S	0.019	m	m	0.007	m	m	100	m	1342
Ghom	7.8	M	8.9	S	4357	S	13	m	m	472	S	29.3	M	0.289	M	m	0.051	m	m	380	m	1220
Nahavand	8.4	S	0.5	m	332	m	6	m	m	328	M	87.8	M	0.025	m	m	0.018	m	m	5184	m	1952
Talesh	8.2	S	0.6	m	207	m	16	m	m	200	m	115.9	S	0.083	m	m	0.042	m	m	5800	m	2074
Semirom	8.3	S	0.3	m	271	m	29	m	m	88	m	87.8	M	0.023	m	m	0.009	m	m	2400	m	195
ShahinShahr	7.5	M	2.5	M	1420	M	29	m	m	120	m	170.8	S	0.033	m	m	0.025	m	m	640	m	268

EC – electrical conductivity; TDS – total dissolved solids; TSS – total suspended solids; BN – bacterial number; Bc – bicarbonates; HR1 – hazard rating according to Bucks *et al.* (1979); HR2 – hazard rating according to Capra and Scicolone (1998); m – minor; M – moderate; S – severe

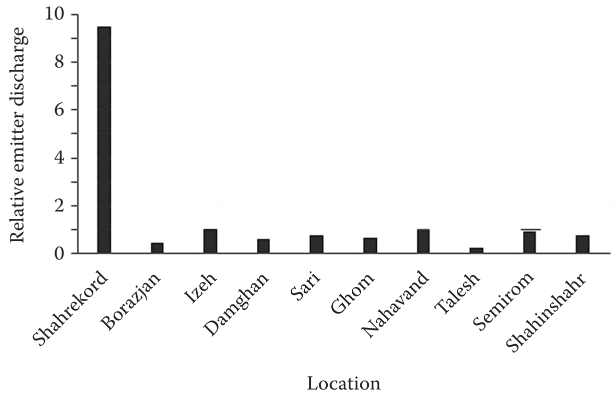

Figure 3. Relative emitter discharge in different locations

agrees with the findings of Liu and Huang (2009). The R values for Borazjan and Talesh sites were low.

The P_{clog} for all sites is presented in Figure 4, indicated by the blank bar. Results show that P_{clog} in Shahrekord, Borazjan, Sari, and Shahinshahr is high. Most sensitive emitters to clogging were found in Shahrekord and Borazjan sites that had the lowest discharges among the studied sites. Ravina *et al.* (1997), Trooien *et al.* (2000), and Liu and Huang (2009) found that emitters with higher discharge are clogged less than those with lower discharge.

Emitter clogging greatly reduces the water distribution uniformity in irrigated fields (Ravina *et al.* 1997; Capra & Scicolone 1998; Puig-Bargues *et al.* 2005; Liu & Huang 2009), which negatively influences crop growth and yield. Ortega *et al.* (2002) evaluated local trickle irrigation units and calculated average emission uniformity, average absolute emission uniformity, and system emission uniformity. According to the criteria proposed by Merriam and Keller (1978) and Capra and Scicolone (1998), EU values in Shahrekord, Borazjan, Izeh, Sari, Nahavand, and

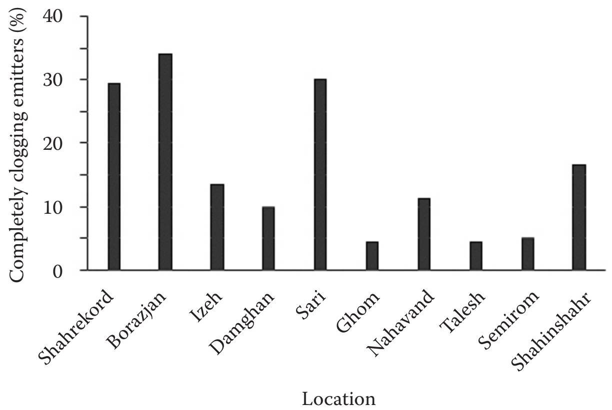

Figure 4. Percentage of completely clogged emitters at different locations

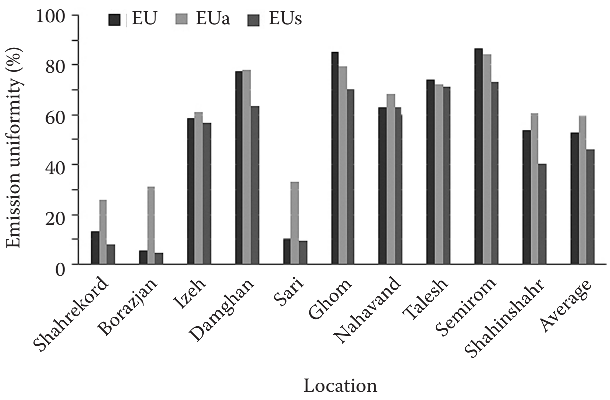

Figure 5. Emission uniformity (EU) of different locations

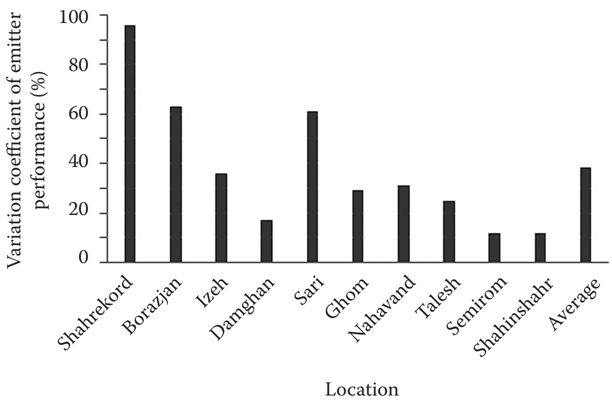

Figure 7. Variation coefficient of emitter performance in different locations

Shahinshahr were poor and low (Figure 5). Average EU values in different locations of Iran are 52.8%, those according to Merriam and Keller (1978) and Capra and Scicolone (1998) were poor and low, respectively. In most cases an incorrect management of the maintenance led to low emission uniformity. Thus, several important problems in the equipment evaluated have been detected: inadequate working pressures, high pressure differences in subunits, emitters clogging, and high manufacturing coefficient of variation of emitters. Inadequate working pressure values are often due to malfunctioning installation and management (pumping station regulation, cleaning status of the filters, etc.) and are, occasionally, a consequence of installation design problems.

According to Capra and Scicolone (1998), Us values of all locations were low and/or mean and also according to ASAE (2003), values of Us in all sites except Damghan, Ghom, Talesh, and Semirom were unacceptable and poor (Figure 6). At different studied locations of Iran average Us value is 61.3%, Us values according to ASAE (2003) and Capra and Scicolone (1998) are considered as poor and low, respectively.

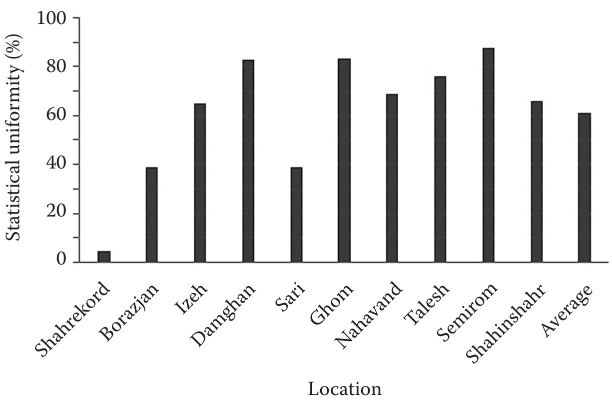

Figure 6. Statistical uniformity of different locations

According to the classification of Capra and Scicolone (1998), V_{pf} values of all studied locations are categorized as low to mean; also according to ASAE (2003), V_{pf} values of all locations except Semirom and Shahinshahr are classified as unacceptable and poor (Figure 7). Average V_{pf} value in different studied locations of Iran is 38.2%, which is, according to ASAE (2003) and Capra and Scicolone (1998), considered as unacceptable and low, respectively.

CONCLUSION

It is necessary to know the uniformity of operating MIS to improve system's performance. The study involved the MIS performance investigation under field conditions in Iran. Average EU, Us, and V_{pf} values determined in different locations (52.8, 61.3, and 38.2%, respectively) are insufficient. The following suggestions and causes of performance reduction in Iranian trickle irrigation systems were identified:

– Inadequate working pressures and high pressure differences in subunits that are often due to malfunctioning installation and management (pumping station regulation, cleaning status of the filters, etc.) and are, occasionally, a consequence of installation design problems.
– Unavailability of completely soluble solid fertilizers or liquid fertilizers created problems in some of the systems manifested as clogging of emitters by solids.
– Most of the farmers did not know how much water should be applied or how to adjust the emitters to achieve the needed application. They did not know a way of measuring the delivery discharge.
– Farmers were not trained in how to maintain trickle irrigation systems (filtration, acidification, and chlorination).

Emitters discharge must be regularly checked during the process of irrigation and in case of identification of clogging, flushing or acid injection or chlorination processes must be applied.

References

Aali K.A., Liaghat A., Dehghanisanij H. (2009): The effect of acidification and magnetic field on emitter clogging under saline water application. Journal of Agricultural Science, **1**: 132–141.

APHA (2005): Standard Methods for the Examination of Water and Wastewater. 21st Ed. American Public Health Association, Washington, DC.

ASAE (1982): Design, Installation and Performance of Trickle Irrigation Systems. Agricultural Engineers Yearbook, Standards of ASAE, American Society of Agricultural Engineers, St. Joseph, 519–522.

ASAE (2003): Field evaluation of micro irrigation systems. EP458. American Society of Agricultural Engineers, St. Joseph, 760–765.

Ayers R.S., Westcot D.W. (1985): Water Quality for Agriculture. FAO, Rome.

Bralts V.F., Kesner C.D. (1983): Drip irrigation field uniformity estimation. Transactions of the ASAE, **26**: 1369–1374.

Bralts V.F. (1986): Field performance and evaluation in trickle irrigation for crop production. In: Nakayama F.S., Bucks S.A. (eds): Design, Operation and Management. Elsevier, Amsterdam.

Bucks D.A., Nakayama F.S., Gilbert R.G. (1979): Trickle irrigation water quality and preventive maintenance. Agricultural Water Management, **2**: 149–162.

Capra A., Scicolone B. (1998): Water quality and distribution uniformity in drip/trickle irrigation systems. Journal of Agricultural Engineering Research, **70**: 355–365.

Ghafari A., Ghasemi V., Depao V. (2004): Agricultural climate zone classification with UNESCO method. Drought and Drought, **12**: 30–35.

Ghinass G. (2008): Manual for performance evaluation of sprinkler and drip irrigation systems in different agroclimatic regions of the world. ICID, New Delhi.

Heydari N., Dehghanisanij H. (2011): Socio-economic and policy-institution issues and challenges in sustainable development of pressurized irrigation systems in Iran. In: 8th Int. Micro Irrigation Congr. October 21, 2011, Tehran.

Keller J., Karmeli D. (1974): Trickle irrigation design parameters. Transcations of the ASAE, **17**: 678–684.

Keller J., Bliesner R.O. (1990): Sprinkle and Trickle Irrigation. AVI Book. Van Nostrand Reinhold, New York.

Liu H., Huang G. (2009): Laboratory experiment on drip emitter clogging with fresh water and treated sewage effluent. Agricultural Water Management, **96**: 745–756.

Merriam J.L., Keller J. (1978): Farm Irrigation System Evaluation: A Guide for Management. Utah State University, Logan.

Nakayama F.S., Bucks D.A. (1991): Water quality in drip/trickle irrigation: a review. Irrigation Science, **12**: 187–192.

Noori J.S., Thamiry H.A. (2012): Hydraulic and statistical analyses of design emission uniformity of trickle irrigation systems. Journal of Irrigation and Drainage Engineering, **138**: 791–798.

Ortega J.F., Tarjuelo J.M., De-Juan J.A. (2002): Evaluation of irrigation performance in localized irrigation systems of semi-arid regions (Castilla-La Mancha, Spain). Agricultural Engineering International: The Cigr Journal of Scientific Research and Development, **4**: 1–17.

Puig-Bargues J., Arbat G., Barragan J., Ramirez de Cartagena F. (2005): Hydraulic performance of drip irrigation subunits using WWTP effluents. Agricultural Water Management, **77**: 249–262.

Ravina I., Paz E., Sofer Z., Marcu A., Schischa A., Sagi G., Yechialy Z., Lev Y. (1997): Control of clogging in drip irrigation with stored treated municipal sewage effluent. Agricultural Water Management, **33**: 127–137.

Sne M. (2006): Micro Irrigation in Arid and Semi-arid Regions – Guidelines for Planning and Design. Israel Export & International Cooperation Institute, Tel-Aviv.

Trooien T.P., Lamm F.R., Stone L.R., Alam M., Rogers D.H., Clark G.A., Schegel A.J. (2000): Subsurface drip irrigation using livestock wastewater: drip line flow rates. Applied Engineering Agriculture, **16**: 505–508.

Wu I.P., Barragan J. (2000): Design criteria for micro irrigation systems. Transactions of ASAE, **43**: 1145–1154.

Yavuz M.Y., DemirelK., Erken O., Bahar E., Deveciler M. (2010): Emitter clogging and effects on drip irrigation systems performances. African Journal of Agricultural Research, **5**: 532–538.

Received for publication February 11, 2013
Accepted after corrections February 14, 2014

Corresponding author:

Dr. Mohammad Zamaniyan, Shahrekord University, Faculty of Agriculture, Department of Water Engineering, Shahrekord, Chaharmahal and Bakhtiari, Iran; e-mail: mohammad.zamaniyan@gmail.com