Technical Evaluation of Drip Irrigation Systems (Case Study of Shahid Rajaayi Agro-Industry – Dezful)

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Abstract: Correct and essential design is one of the important factors in development and improvement of pressurized irrigation systems. This research was performed using Miriam-Keller method in order to investigate drip irrigation system implemented in Shahid Rajaayi Agro-Industry, Dezful. To do this, five systems were selected as a drip irrigation system. These systems were different in terms of lateral pipe layout and nominal discharge of drippers. Drippers used in these systems were Compensating Emitters with 2.2, 4 and 8 liters/hour Flow rates and had parallel and pig-tail configurations. To evaluate irrigation systems, Christiansen Uniformity Coefficient (CU), Emission Uniformity (EU), Potential Efficiency of Low Quarter (PELQ) and Actual Efficiency of Low Quarter (AELQ) parameters were used. Mean values of the above parameters in the evaluated systems were obtained 95.12%, 91.68%, 82.91% and 91.2%, respectively. Among systems evaluated, System D from Plot 110, with pig-tail lateral layout and 8 liter/hour drippers was selected as the best system in terms of measured parameters. Values of Uniformity Coefficient (CU), Emission Uniformity (EU), Potential Efficiency of Low Quarter (PELQ) and Actual Efficiency of Low Quarter (AELQ) for this system were 98, 95.8, 86.22 and 95.8 percent, respectively. Values of Emission Uniformity obtained for the evaluated five systems were in "Perfect" class. Low difference of values of PELQ and AELQ indicates good management of these systems and suitable design of them.
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1. Introduction

Because of limitation of fresh water resources, their gradual contamination and increase of population and water demand for various uses, applying correct and intelligent management of water resources on local, regional and national scales for optimum use and logical protection is inevitable. Considering the increasing trend of this demand, climatic conditions of country and over 90 % consumption of available water in agriculture sector (Jahani, 1998), there is no way except paying specific attention and adopting logical approach to low water consumption practices. One of irrigation methods in which considerable savings can be created in water consumption and other costs by low consumption of water and most control, particularly for trees, is drip irrigation method. Drip irrigation involves slow distribution of water on surface or under soil as separate drips, continuous drips, narrow flow or fine spray by drippers located along water transport line (Charles and Stewart, 2007). Although drip irrigation is one of the new irrigation methods in which, considering its inherent capabilities, most control can be exerted on one hand, and irrigation efficiency can be maintained at high level by informed management on the other, if necessary precision is not used in design, implementation, operation and maintenance of system sometimes problems caused by it may be very serious. In drip irrigation, the more uniform the discharge of drippers, the higher the efficiency of system. Three important factors influencing it are uniformity, pressure and physical characteristics of emitters. Besides these factors, system management is also an important factor that should be evaluated. System management plays an important role in application efficiency and economic performance of system by regulating irrigation hours and runs, controlling pressures, monitoring system performance and correct usage of fertilizer and other chemical material. Therefore, system functioning status should be evaluated (Fit et al, 1990). Analysis of each irrigation method, based on measurements in real conditions of field and during natural work, is called irrigation evaluation in orchard. Since agricultural issues are influence by numerous factors and any change should be made with much care, and considering climatic, cultural, social and economic conditions of regions, it is useful to evaluate performance of these methods to identify existent problems and use resultant experiences in future (Ghasem-zadeh Mojaveri, 1990).

Goals of evaluating pressurized irrigation systems can be summarized as follows:

- Determination of real efficiency of system

- Determination of maximum efficiency of system or performance potential of irrigation method in present conditions
- Determination of criteria of comparison between various methods
- Evaluation of accuracy of design parameters.

Studies that International Irrigation and Drainage Committee have performed in issues and problems of drip irrigation suggest that in all countries, one of the essential problems in drip systems is clogging of drippers. Clogging is due to using poor quality water or selection of inappropriate adjustment system which results in non-uniform distribution of water along lateral pipes and consequently reduction of irrigation efficiency. Risk of dripper closure increases system operation and maintenance costs including costs of controlling drippers and their repair or replacement (Nasrollahi, 2009). Mikhak Biranvand (2013) evaluated six drip irrigation systems that have spent at least four cultivation seasons in Khorram Abbad. Mean values of Christiansen Uniformity coefficient (CU), distribution uniformity (DU), potential efficiency of low quarter (PELQ) and real efficiency of Application Efficiency in low Quarter (AELQ) parameters for these systems were 81.23, 72.41, 45.11 and 48.33 percent, respectively.

Alikhani Mehwar and Zareei (2009) investigated performance of drip irrigation and influence of sand and disk filters on it. Their results showed that clogging probability is present in some drippers in spite of presence of sand filters in micro-irrigation system. Sand filter layers are disturbed due to reverse washing, which influences pressure drop and amount of particulates in passing water as well as system functioning time. Finally, performance of disk filters compared to that of sand filters was evaluated in term of rate of better water treatment. Naderi (2009) examined water quality in drip irrigation system which showed iron and magnesium with concentration at 0.1 mg/l levels can cause clogging of drippers. Due to lack of deep penetration and washing of salts in micro-irrigation, in case of irrigating by saline water, salt accumulate at surface layer of soil. So, during design of system capacity, it is important to consider leaching requirements. On the other hand, waters containing low salt with electrical conductivity less than 0.5 mmhos/cm which is used in non-saline soils with low to medium sodium absorption ratios can disturb soil penetrability.

Alizadeh et al (2009), in technical evaluation of strip drip irrigation systems implemented in row cultivations of Chenaraan that was performed on parameters required in evaluation such as uniformity coefficient efficiency (EU), potential efficiency of low quarter (PELQ), real efficiency of Application Efficiency in low Quarter (AELQ) parameters and maximum pressure difference in systems, showed that discharge of drippers were lower than its nominal value in half of fields studied due to low pressure or clogging. Baradaran Hazaveh (2005) evaluated six drip irrigation plans and calculated uniformity coefficient, potential efficiency of low quarter (PELQ) and real efficiency of Application Efficiency in low Quarter (AELQ) parameters. According to results of evaluation, PELQ and AELQ parameters were calculated 59 and 57 percent, respectively. Uniformity extent in this evaluation was calculated 78 percent. Finally, it was concluded that performance of the evaluated systems was medium. Piri (2009) examined eight drip irrigation systems in Sarbaaz city that have spent at least three cultivation seasons. Mean values of Christiansen Uniformity coefficient (CU), distribution uniformity (EU) efficiency, potential efficiency of low quarter (PELQ) and real efficiency of Application Efficiency in low Quarter (AELQ) parameters were obtained 93, 88.15, 68.72 and 78.1 percent, respectively.

Marham et al (2010) examined clogging of drippers and its effects on performance of drip irrigation systems. In this study, to determine clogging level of drippers, drippers of irrigation systems of a number of fields in Canada were used and their effect on irrigation performance was observed. Drippers collected from different fields were initially inspected and then tested at 50, 100, 150, 200, 250 and 300 kPa pressures in hydraulic laboratory. Results showed discharge changes coefficient of drippers not used and drippers used for one, two and three years were in ranges of 0.43 and 0.63, 0.43 and 0.69, 0.48 and 0.58, and 0.56 and 0.73. Discharge changes coefficient of drippers in all laterals used for one year was determined at 5% level. Discharge changes coefficient of drippers of two laterals used for two years and all laterals used for three years were out of 5% range.

2. Materials and Methods

Dezful is one of cities of Khuzestan Province in southwest of Iran which is located next to Dez river. It has hot and wet climate. It reaches to Andimeshk and Aligoodarz in north, Lali and Gotvand in east and Shush in south and west. Shahid Rajayi agro-industry of Dezful is located 22 kilometers from Dezful-Safi Abaad Road and 7 kilometers from Kootian, in coordinates of 22 degrees and 13 minutes north and 48 degrees and 28 minutes east. Area of orchards of Shahid Rajaayi Agro-Industry Company is 130 hectares. Dominant soil texture of lands is announced Clay Loam and

Silty Clay Loam. Water resource available in the area consists of Dez Irrigation network, a part of Ajirab River and wells present in the area. In this plan, five systems (A, B, C, D and E) were studied. Systems A, B, C and D are located in Plot 110 of Shahid Rajayi Agro-Industry and irrigated from a central control station which includes eight disk filters. System E is from Plot 97 of Agro-Industry which is irrigated from Ajirab River and its central control system includes hydro-cyclone, sand tank and four disk filters.

Table 1: characteristics of the studied orchards and their implemented systems

System characteristics	A	B	C	D	E
Orchard area (hectare)	7	3	1.5	3.5	2
Irrigation system type	Parallel	Pig-tail	Parallel	Pig-tail	Pig-tail
Dripper type	Self-Compensation	Self-Compensation	Self-Compensation	Self-Compensation	Self-Compensation
Dripper discharge (lit/hr)	4	4	2.2	8	8
Number of drippers for tree	14	10	16	3	12
Water source	Well	Well	Well	Well	Ajirab River
Trees configuration	6*6	7*7	7*7	6*6	7*7
Shading percentage(%)	61	69	70	17	62.65
Irrigation frequency	2	2	2	2	2
Irrigation hour	5	9	10	4	4

Selection of sampling points was performed based on Miriam-Keller method. In this method, first one of the working manifolds was selected. Four Lateral pipes on these manifolds were selected at initial part of manifold, one-third distance from initial part, two-third distance from initial part and at the end of manifold pipe. Then, four trees were selected from the mentioned points on each Lateral pipe. This way, 16 trees were selected and for each tree, four readings of dripper discharge were made. Pressures at two ends of four selected Lateral pipes were measured. From above phases, 8 pressures at two ends of Lateral pipe and 64 drippers were obtained for calculation of water volume in place of 16 trees for distinct pour points. Mean discharge of drippers and distribution uniformity were calculated from volumes obtained.

Minimum Inlet Pressure to Branch Pipe (MLIP)

Among all branch pipes that intake water from one manifold, one has minimum inlet pressure. This value is called minimum inlet pressure to branch pipe on the operating manifold. Its location depends on frictional loss and topographic status (Alizadeh, 2009).

Efficiency Reduction Factor (ERF)

If pressures of the operating manifolds are not the same, efficiency of the whole system will be lower than that of manifold examined. However, in most systems, instruments for controlling or regulating pressure are installed at inlet of manifold. To estimate efficiency reduction factor, minimum inlet pressure of Lateral pipe along each manifold and throughout the system is used which is obtained from the following relation (Ghasem zadeh Mojaveri, 1990):

$$ERF = \frac{(MLIP) + 1.5(MILP_{min})}{2.5(MILP)} \quad (1)$$

Where ERF denotes efficiency reduction factor and $MLIP_{min}$ is the lowest inlet pressure of Lateral pipe in whole system (meter).

Water Distribution Uniformity Efficiency in System (EUs)

Water Distribution Uniformity Efficiency (EU) is necessary for determination of system efficiency and estimation of gross depth of irrigation water. System EUs is a function of pour uniformity in examined area and pressure changes in the whole system. When experimental data of dripper discharge belongs only to one manifold, EU_T of the experiment is calculated from equation (2) (Ghasem zadeh Mojaveri, 1990):

$$EU_t = \frac{q_n}{q_{avg}} \times 100 \quad (2)$$

Where:

EU_t= distribution uniformity of drippers in region of manifold examined (percent)
q_n= low quarter discharge of drippers in region of manifold examined (L/h)
q_{avg}= mean discharge of all drippers in region of manifold examined (L/h)
Considering the definition of efficiency reduction factor (EU_s), it is estimated from the following relation that:

$$EU_s = ERF \times EU_t \quad (3)$$

Where:
EU_s= distribution uniformity in drip irrigation system (percent)
ERF = efficiency reduction factor
Efficiency of drip irrigation system can be evaluated in terms of value of (EU_s) according to table 2 (Alizadeh, 2009).

Table 2: description of system efficiency based on system distribution uniformity

System performance	System distribution uniformity (EU_s)
Perfect	>90
Good	80-90
Medium	70-80
Poor	<70

Table 3: classification of drippers based on CV (Alizadeh, 2009)

Dripper type	Construction changes coefficient	Group
Pin Point Drippers	<0.05	Perfect
	0.05-0.07	Medium
	0.07-0.11	Border of medium and poor
	0.11-0.15	Poor
	>0.15	unacceptable

Actual Efficiency of low Quarter Application (AELQ)

Concept of AELQ: since in drip irrigation in regions receiving the least water there is no reason for wasting water through evaporation and deep penetration. Thus, in drip irrigation, Actual Efficiency of low Quarter of water Application is defined as relation (4):

$$ALEQ = ERF \times EU_t \quad (4)$$

Potential Efficiency of Low Quarter (PELQ)

In drip irrigation, PELQ concept is different from what is used in sprinkler irrigation in which only a part of soil is wetted and so SMD should be separated constantly. Estimation of SMD is difficult because a part of wetted soil is always in farming capacity (FC) range. As a rule, points of earth surface that receive the least amount of water should be irrigated with 10 percent more water than estimated value of evapotranspiration or SMD.
For drip irrigtation system, PELQ is obtained from equation (5):

$$PLEQ_t = 0.9 \times EU_t \quad (5)$$

$$PLEQ_s = 0.9 \times ERF \times EU_t \quad (6)$$

$PELQ_t$ = Potential Efficiency of Low Quarter Application in region of manifold studied (percent)
EU_t= distribution uniformity of drippers in region of manifold studied (percent)
$PELQ_s$= Potential Efficiency of Low Quarter Application in system studied (percent)
ERF= efficiency reduction factor

In ideal irrigation in which SMD plus 10 percent extra water is added to the regions received less water, AELQ=PELQ (Ghasemzade Mojaver, 1990). In this research, equations (5) and (6) are used to calculate PELQ.

Uniformity Coefficient (CU) and Distribution Uniformity (DU)

Water application uniformity in orchard is a measure based on which it can be determined how water has been distributed on surface (Asugh and Kiker, 2002). If amount of water outgoing from each dripper is considered water distribution measure in orchard, Christiansen Uniformity Coefficient (CU_t) and water distribution uniformity in lower quarter (DU_t) are obtained as follows (Alizadeh, 2005):

$$CU_t = \left(1 - \frac{\sum |D_i - \bar{D}|}{\bar{D} - n}\right) \quad (7)$$

Where:
CU_t= Christiansen uniformity coefficient of experiment block (%)
D_i= discharge obtained from each dripper (L/h)
$\bar{D}$ = mean value of measured discharges (L/h)
n = number of observations

$$DU_t = \frac{D_q}{\overline{D}} \quad (8)$$

DU_t= distribution uniformity in low quarter of experiment block (%)
D_q= mean discharge in one-fourth of the lowest measured values (L/h)
$\overline{D}$ = mean value of measured discharges in the region of the studied manifold (L/h)

3. Results and Discussion

Loss in Central Control Station (Filtration)

In drip irrigation systems a considerable part of pressure supplied to system is lost in water passing rout through various filters (hydro-cyclone, sand and disk filters). Because of closure of pores in sand and disk filters, pressure drop rate in them should be measured and they should be cleaned manually or automatically. Systems A, B, C and D, which are located in plot 110, intake water from a central control station which includes eight disk filters. Pressure drop was 3 meters. Since the central control station is more suitable with drop less than 3.5 meters (Anonymous, 1997) it can be concluded that filtration systems in these farms have had acceptable performances.

System E was located in Plot 97 which includes hydro-cyclone, sand tank and four disk filters. Life of this system was more than that of central control station of other studied systems, so its equipment had more depreciation which caused more pressure drop in system. Therefore, its pressure drop was 5.2 meters which indicates that, based on guidelines of Improvement and Development of Pressure Irrigation Methods Center, central control system of orchard has inappropriate performance and needs repair and maintenance.

Table 4: characteristics of inlet and outlet pressure in pumping station in Plot 110 and Plot 97

Plot No	Inlet pressure (m)	Outlet pressure (m)	Pressure difference (m)
Plot 110	30	27	3
Plot 97	30	24.8	5.2

Results of Water Quality Evaluation

Results of well water evaluations indicated that electric conductivity of water was 0.74 ds/meter and sodium absorption ratio was 1.16 which is in class C2S1 in Wilcox Classification. Well water acidity was calculated 6.3, which is suitable for agricultural uses. Experiments on water of Ajirab River indicated that water electric conductivity was 0.775 ds/m and sodium absorption ratio was 1.23, which is in class C2S1 in Wilcox Classification. Well water acidity was calculated 6.3, which is suitable for agricultural uses.

Table 5: results of chemical analysis of well water in Plot 110 and Ajirab River

Sampling site	Co3	Hco3	Mg	Ca	Na	Cl	SAR	PH	EC	Irrigation class
Unit	Meq/lit						Ds/m			
Well in Plot 110	0	4.5	2.1	4.3	2.07	1.9	1.16	6.3	0.74	C2S1
Ajirab River	0	4.86	1.77	4.01	2.07	2	1.23	7	0.775	C2S1

Pressure Distribution in Irrigation Unit

In drip irrigation systems, lengths of lateral pipe and manifolds are measured for conditions in which changes of discharge between drippers working simultaneously in one irrigation unit is usually about 10 percent. Considering relationship between discharge and pressure of drippers, if lands are flat and level, pressure changes in irrigation unit should not be more than 20 percent. From this amount, 55 percent belongs to lateral pipe and 45 percent belongs to manifold (Ghasemzadeh Mojaveri, 1990). Table 6 indicates pressure distribution in irrigation units.

Table 6: pressure distribution in branch pipes of the studied system

System	A	B	C	D	C
Maximum pressure in lateral pipe (m)	16.3	16.2	12	16.3	16.3
Minimum pressure in lateral pipe (m)	13	13.5	11	14.7	14.7
Average pressure in lateral pipe (m)	14.9	14.97	11.44	15.54	15.54
Percentage of pressure changes in lateral pipe	15.5	16.6	8.3	6	10

Data in table 6 indicates that all five orchards evaluated had pressure changes in standard ranges, which suggests appropriate design of length of branch pipeline of systems. System D has lowest pressure changes due to its pig-tail configuration and low number of drippers. Highest percentage of pressure changes belong to system B due to its longer branch pipe than that of other systems studied.

Percentage of Wetted Surface

Average wetted surface in systems evaluated has been lower than recommended value for arid and semi-arid areas (33% <PW<66%) and varies from 31.8 percent in system A to 12 percent in system D. to increase wetted surface, it is suggested that, by increasing distance between drippers, avoiding placing branch pipes on each other in pig-tail configuration and providing suitable distance between branch pipes in parallel configuration, wetted surface percentage is increased.

Water Yield of Drippers

The most important parameter influencing performance of a drip irrigation system is water yield of drippers, which depend on numerous factors including type of drippers, construction changes coefficient, system pressure and water quality. In table 7, mean of measured discharge and percentage of discharge changes in systems evaluated are assessed.

Table 7: mean value of measured discharges and percentage of discharge changes in evaluated systems

System	A	B	C	D	E
Nominal discharge of dripper (lit/hr)	4	4	2.2	8	8
Mean value of measured discharge (lit/hr)	4.11	4.03	2.08	7.95	6.65
Changes of measured discharge (percentage)	27	9	11	13	9

In system E, due to absence of initial washing of pipes before operation, mud in pipes caused clogging in drippers. As indicated in table 7, average discharge measured (6.65 liters/hour) is 1.4 L/h less than nominal discharge of drippers used (8 liters/hour).

Parameters Calculated In Evaluation of Drip Irrigation Systems

Values obtained from evaluation were calculated considering discharge distribution and pressure in irrigation unit and using equations. These values are reported in table 8. Rating of each parameter compared to other systems is written next to it and the lowest rating belongs to the best system. Systems in range of rating 8 are classified as the best systems and those in rating range of 40 are classified as the poorest systems.

Table 8: results obtained from evaluation of systems studied and rating of parameters

Parameter	A	B	C	D	E
Discharge reduction percentage	(5) 9.7	(2)2.4	(3)3.97	(1)2.01	(4)5.9
Uniformity coefficient (CU)	(5)90.4	(3)95.3	(2096	(1)98	(4)94.1
Distribution uniformity (DU)	(5)80.6	(2)95.1	(3)94.1	(1)96.3	(4)90
Coefficient of Variation (CV)	(5)12.9	(3)6	(2)5.7	(1)3	(4)7.5
Efficiency of water distribution uniformity (EU_t)	(5)85.8	(2)94.2	(3)93	(1)95.8	(4)89.8
Efficiency of water distribution uniformity in system (EU_s)	(5)84.8	(2)94.2	(3)93	(1)95.8	(4)88.2
PELQs	(5)76.3	(2)84.78	(3)83.7	(1)86.22	(4)79.4
AELQs	(5)84.8	(2)94.2	(3)93	(1)95.8	(4)88.2
Total ratings of each system	40	18	22	8	32

By SCS definition, if efficiency of water distribution uniformity of drippers in the whole system (EUs) is more than 90percent, system performance is perfect and if it exceeds 80 percent, system performance is described "good". In systems A and E, efficiency of water distribution uniformity was measured more than 80 percent and these systems were described "good" in terms of the above parameter. Ortega et al (2004) evaluated distribution uniformity efficiency in semi-arid areas of Spain as 82 percent which is lower than average distribution uniformity efficiency (91.6%) in systems studied.

Systems D and A have lowest and highest values of CV with value 3% and 12.9%, respectively which, according to table 3, are perfect and poor values, respectively.

Systems D and A have the highest and lowest AELQs values, 95.8 and 84.81 percent, respectively which suggests these values compared to those obtained by Mikhak Biranvand (2012) and Piri (2009), which are 48.33 and 78.1% respectively, have higher efficiency.

Mean value of PELQs for systems studied was obtained 82.1 percent. This value, as compared to that obtained by Baradaran Hazaveh (2005), Mikhak

Biranvand (2012) and Piri (2009), which were 57, 45.11 and 69.72% respectively, indicates that systems studied have higher PELQ that suggests appropriate design management and appropriate design of these systems.

Low difference between two parameters PELQs and AELQs indicated good management of these systems.

Considering results in table 8 and rating obtained, systems D, B, C, E and A are evaluated as the best to the poorest systems with total ratings of 8, 18, 22, 32 and 40, respectively.

In table 9, results of one-sample t-test of measured discharges and discharge provided by producer for all systems are presented.

Table 9: results of monomial t-test

System	Nomial discharge (lit/hr)	t-test statistic	Freedom degree	P-Value	Average difference	Confidence band 95 %	
						Lower limit	Higher limit
A	4	1.788	63	0.079	0.1188	-0.140	0.252
B	4	0.525	63	0.132	0.0463	0.0144	0.107
C	2.2	-7.946	63	0.000	-0.118	-0.148	-0.088
D	8	-1.375	47	0.176	-0.048	-0.118	0.220
E	8	-21.407	63	0.000	-1.335	-1.46	-1.210

If value of P-Value is higher than 0.05, there is no significant difference between average value of measured discharges and discharge provided by producer. Considering table 9, drippers used in systems C and E had clogging and significant discharge reduction. Reasons of this significant difference in system C were low quality of construction and poor management of system in providing operating pressure which caused lower discharge of emitters compared to discharge provided by factory. In system E, central control station and filtration station had inappropriate performance due to their long life (10 years).

Conclusions

Average values of Christiansen uniformity coefficient (CU), distribution uniformity efficiency (EU), potential efficiency of low quarter application (PELQ) and actual efficiency of low quarter application (AELQ) parameters in systems evaluated were obtained 95.12, 91.86, 82.91 and 91.2 percent, respectively systems D and A had highest and lowest uniformity coefficient (CU) with 90.33 and 98 percent, respectively. Both are perfect values. Systems D and A have highest and lowest values of water distribution uniformity efficiency in system (EU_S) with 95.8 and 84.8 percent, respectively, which were among perfect and good values, respectively. Systems D and A have highest and lowest values of potential efficiency of low quarter application (PELQ) with 86.22 and 76.33 percent, and highest and lowest values of actual efficiency of low quarter application (AELQ) with 95.8 and 84.81 percent, respectively. All five systems studied were assessed good to perfect. Considering data obtained from other systems, systems A and D were evaluated as the best and the poorest systems, respectively.

To improve and increase efficiency of systems studied, it is recommended that:

Regular inspection of drippers, fittings and their functioning is performed and, if necessary, they should be replaced and lateral pipes should be flushed to extract accumulated material. By repair and replacement of equipment of filtration system of Plot 97, it is possible to increase efficiency of drip irrigation systems of this Plot. It is possible to prevent clogging of disk filters in Plot 110 by adding hydro-cyclone to filtration system of this Plot.

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